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*The Journal of*

# THE ROYAL AERONAUTICAL SOCIETY

CONTENTS OCTOBER 1948

*SOME ECONOMIC FACTORS IN CIVIL AVIATION*
PETER G. MASEFIELD, M.A., F.R.AE.S., M.I.AE.S., G.INST.MECH.E.

*CORRESPONDENCE*

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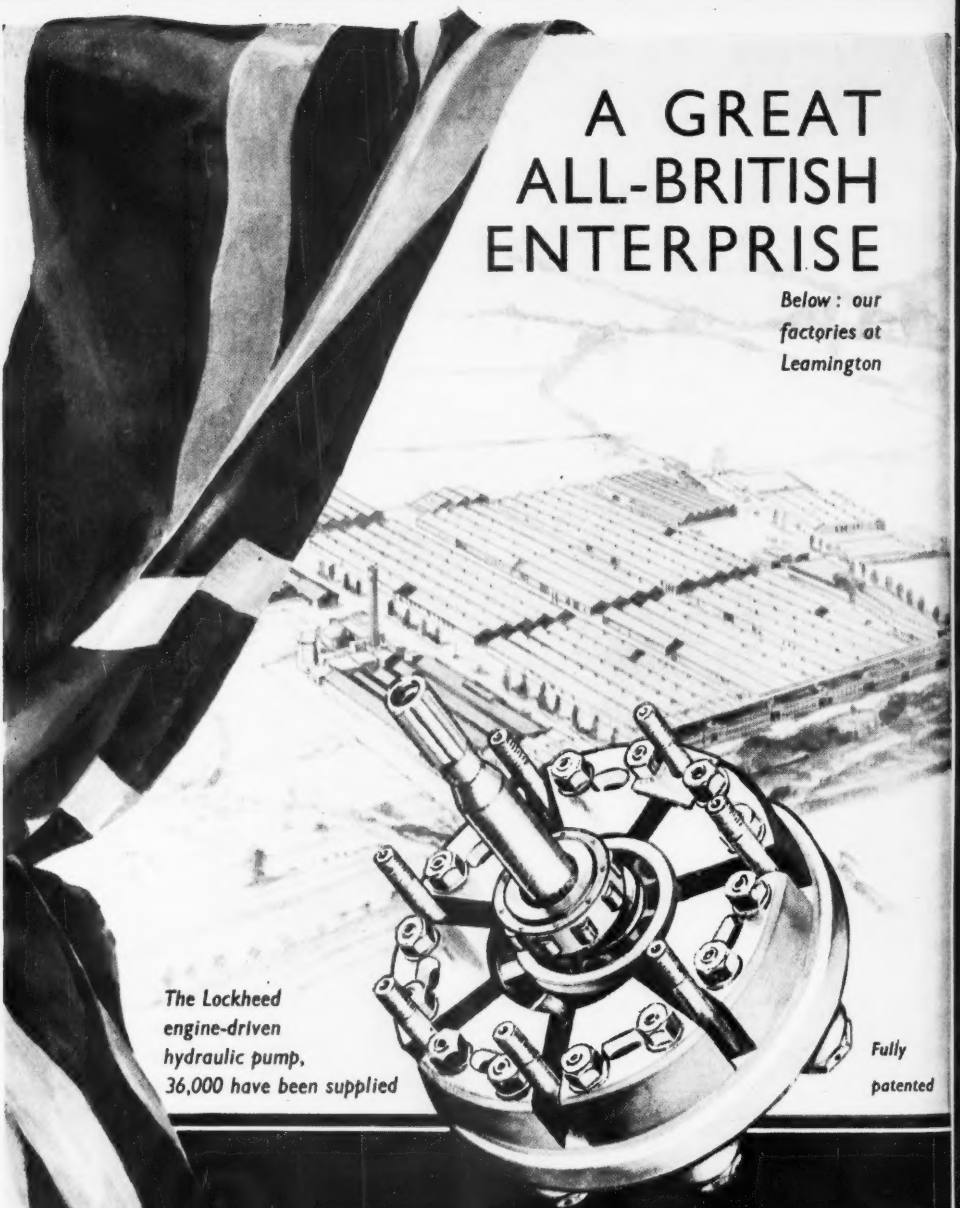

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# OCTOBER NOTICES 1948

## JOURNAL PREMIUM AWARDS

**The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.**

## CONTENTS OF THE OCTOBER JOURNAL

Fourth British Commonwealth and Empire Lecture—Some Economic Factors in Civil Aviation—with Emphasis on Civil Aircraft and Their Prospective Trends of Development, Peter G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., Grad.Inst.Mech.E.

Correspondence.

## CONVERSAZIONE—29th OCTOBER 1948

The Society will hold a Conversazione on Friday, 29th October 1948 from 8.0 p.m. until midnight at the Science Museum, South Kensington, by kind permission of the Director, Dr. H. Shaw.

The President, Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., F.I.Ae.S., and Mrs. Roxbee Cox, will receive members and their guests. During the evening a number of pre-war aeronautical films will be shown and, for those who wish to dance, dance music will be played from 9.30 p.m. to midnight.

Tickets, including Buffet, will be £1 1s. 0d. each (£2 2s. 0d. for a double ticket). FOR GRADUATE AND STUDENT MEMBERS OF THE SOCIETY ONLY, the price of a double ticket will be £1 11s. 6d.

A distinguished company will be present and the President and Council hope that members and their friends will make a special effort to attend, especially from the many Branches of the Society.

Application for tickets must be made on the form enclosed with the September or October Journals and Monthly Notices. Early application is advisable.

## ANGLO-AMERICAN AERONAUTICAL CONFERENCE 1949

Arrangements are now being completed for the Aeronautical Conference to be held in 1949.

The Society has been in close consultation with the Institute of the Aeronautical Sciences and a number of lectures have already been arranged. The Conference will spread over five days and will be followed by a number of visits to aircraft firms and to Langley Field and elsewhere.

Recently Mr. A. D. Emil, representing the Institute of the Aeronautical Sciences, paid a visit to England and at a dinner given to him by the Council he explained what steps the Institute were taking to make the Conference an outstanding event in the year 1949 in the history of the Institute. Mr. Emil handed to the Council, on behalf of the Council of the Institute, the following resolution:—

"WHEREAS, it is deemed highly desirable to augment the cordial relations that now exist between the Institute of the Aeronautical Sciences and the Royal Aeronautical Society of Great Britain, and

WHEREAS, the advancement of the aeronautical sciences in the respective countries can best be served by a periodic inter-change of views on various technical matters by representatives of the two Societies,

BE IT THEREFORE RESOLVED, that the President of the Institute of the Aeronautical Sciences, on behalf of the Council of the Institute, extend to the President and Council of the Royal Aeronautical Society an invitation to designate representatives to meet with the Institute of the Aeronautical Sciences in New York City between 22nd May and 6th June or any other dates that may be mutually agreed upon, to discuss problems of common interest in the field of the aeronautical sciences."

The following reply from the Council has been sent to the Institute:—

"The President and Council of the Royal Aeronautical Society welcome the invitation of the President of the Institute of the Aeronautical Sciences to designate representatives to meet with the Institute of the Aeronautical Sciences in New York City between 22nd May and 6th June 1949 to discuss problems of common interest in the field of the aeronautical sciences.

The President and Council are convinced that by such an inter-change of views on technical matters by representatives of the two Societies, the cordial relations which now exist between the Institute of the Aeronautical Sciences and the Royal Aeronautical Society will be enhanced and their objects, namely, the increase in knowledge of aeronautical science and engineering, will be furthered. They have therefore great pleasure in accepting the invitation of the Institute."

The second Conference of the two Societies will have read before it some twenty papers covering a wide range of technical activity, and it is hoped that a good British representation will be possible in addition to those who have accepted the Council's invitation to lecture. The Council feel that the opportunity given by these Conferences to make the personal acquaintance of "opposite numbers" on each side of the Atlantic is one which should be taken every advantage of, as such personal contacts will prove of increasing benefit to aeronautical engineers both in this country and the U.S.A.

Members who propose to attend the Conference should inform the Secretary as quickly as possible.

## LECTURE—11th NOVEMBER 1948

On Thursday, 11th November 1948 a paper entitled "French Aircraft Gas Turbines" by M. Destival of Cie Electro-Mecanique will be read before the Society at 6 p.m. at the Institution of Civil Engineers, Great George Street, W.1. (Tea at 5.30.) The Lecture will be read in English by M. Bidard, Engineer in Chief, Cie Electro-Mecanique.

## MEMBERS NEW APPOINTMENTS

The following members have recently taken up new appointments:—

Dr. H. Roxbee Cox, B.Sc., D.I.C., F.R.Ae.S., F.I.Ae.S.—Chief Scientist to Ministry of Fuel and Power.

Mr. H. Constant, F.R.Ae.S.—Director of the National Gas Turbine Establishment.

Mr. J. V. Connolly, B.E., A.F.R.Ae.S.—Professor of Production Engineering at College of Aeronautics, Cranfield.

Mr. S. R. Lewis, B.Sc., A.F.R.Ae.S.—Senior Lecturer in Component and Detail Stressing of Aircraft Structures at College of Aeronautics, Cranfield.

## HELICOPTER ASSOCIATION JOURNAL

Members of the Society who would be interested to receive the Journal of the Helicopter Association are asked to inform the Secretary of the Royal Aeronautical Society. If enough applications are received a reduction in the price of the Helicopter Association Journal will be made to them.

## LAPEL BADGES

Small lapel badges of the Society's crest in metal silver-plated, and in light and dark blue enamel, will be available shortly for members. The cost of each badge will be 3/6 (including postage).

## LECTURES ON INTERNAL COMBUSTION TURBINES

A special series of six lectures will be delivered at the Institution of Mechanical Engineer's, Storey's Gate, St. James's Park, S.W.1, by the staff of the National Gas Turbine Establishment on 3rd and 4th November 1948. These lectures are a sequel to those delivered in February 1946 at the same Institution.

Admission will be by ticket only, and separate tickets will be issued for each of the two days. Any member of the Royal Aeronautical Society who wishes to attend should write to the Secretary at the Society's address, stating which particular lecture or lectures they wish to attend, so that tickets may be obtained accordingly.

In case any ticket holder is unable to attend it is understood that he will return the ticket(s) without delay to the Secretary of the Institution of Mechanical Engineers.

It is hoped that copies of the lectures will be available immediately after the meetings. The programme is as follows:—

**Wednesday, 3rd November 1948**

11 a.m.—Lecture on " The Prospects of Land and Marine Gas Turbines," by Hayne Constant, M.A., F.R.Ae.S., M.I.Mech.E., F.R.S.
*Chairman*: The President, Capt. (E.) W. Gregson, R.N.R., M.Sc., M.I.Mech.E.

2 p.m.—Lecture on " The Part-load Performance of Various Gas Turbine Engine Schemes," by D. H. Mallinson, B.Sc., and W. G. E. Lewis, B.Sc., G.I.Mech.E.
*Chairman*: Air Commodore Sir Frank Whittle, K.B.E., C.B., M.A., F.R.Ae.S., Hon.M.I.Mech.E., F.R.S.

3.45 p.m.-4.30 p.m.—Tea interval.

4.30 p.m.—Lecture on " The Fuel Problem in the Gas Turbine," by P. Lloyd, M.A.
*Chairman*: Air Commodore Sir Frank Whittle, K.B.E., C.B., M.A., F.R.Ae.S., Hon.M.I.Mech.E., F.R.S.

**Thursday, 4th November 1948**

11 a.m.—Lecture on " The Performance of Axial-Flow Turbines," by D. G. Ainley, B.Sc.
*Chairman*: H. Roxbee Cox, Ph.D.(Lond.), F.R.Ae.S., F.I.Ae.S., M.I.Mech.E.

2 p.m.—Lecture on " Heat Flow in the Gas Turbine," by A. G. Smith, B.Sc.
*Chairman*: Sir Harry R. Ricardo, B.A., LL.D., F.R.Ae.S., M.I.Mech.E., F.R.S.

3.45 p.m.-4.30 p.m.—Tea interval.

4.30 p.m.—Lecture on " Three-dimensional Flow Theories for Axial Compressors and Turbines," by A. D. S. Carter, B.Sc., Grad.R.Ae.S., G.I.Mech.E.
*Chairman*: Sir Harry R. Ricardo, B.A., LL.D., F.R.Ae.S., M.I.Mech.E., F.R.S.

## GRADUATES' AND STUDENTS' SECTION—NOTICES

The Lecture programme for the Autumn Session as given elsewhere in these Notices includes a discussion on papers read before the Section on Tuesday, 7th December 1948. The Secretary of the Section would be grateful if Members willing to prepare and read short papers (of about 15-20 minutes in length) would write to him, M. C. Campion, 6a Mildenhall Road, Clapton, E.5. Papers of 1,000-1,500 words for the Section's leaflet in the Journal will also be welcomed.

As an experiment refreshments will be obtainable at moderate charges at 7 p.m. before the Section's Lecture on Wednesday, 10th November at the Society.

## ALL DAY DISCUSSION ON HELICOPTERS

The following are summaries of the short papers which will be read at the all day Discussion on Helicopters, a Joint meeting with the Helicopter Association, which will be held on Saturday, 20th November 1948 at the Institution of Civil Engineers.

MORNING SESSION

### General Problems of the Helicopter for Civil Use—The Operational Point of View by W/Cdr. R. A. C. Brie, A.F.R.Ae.S.

*Introduction*

During the two years which have elapsed since the helicopter was first given a certificate for civil use, the problems associated with its operation have become sufficiently well defined to enable their nature to be discussed with reasonable facility. While no fundamental deficiency exists in a basis configuration, it has been advantageous at this stage of development that the operational background has been professional, rather than amateur. Difficulties experienced are attributable to lack of refinement in detail design. Close liaison between constructor and user has given the aircraft a reasonable chance to establish itself and prove its value under strictly controlled conditions of inspection and operation. Essentially a product of the engineer, the mechanical layout of the helicopter is comparable to that of normally accepted means of surface transport. That it is capable of becoming airborne with adequate control, and can be operated from extremely confined areas under turbulent conditions, is evidence of the skill with which the pioneers have solved the major problems associated with the functioning of the rotor system.

*General Problems*

Problems discussed fall under headings of—Engineering, Flight Characteristics and Operation. Each has a direct association with, and influence on, the other. Appropriate sub-headings include maintenance, piloting and performance.

*Engineering*

Mechanical complexity, multiplicity of moving parts, and vibrational characteristics of the rotor system make the helicopter critical to small departures from allowable tolerances on linkages. The permissible working life of the blade hinge bearings is too limited and compactness is achieved at the expense of reliability, comfort and performance. Because of this, utilisation is impaired, inspection schedules are prolonged, and the costs of operation are increased. To accelerate inspection and the replacement of parts, easily removable panels, jacking and sling points, hand-grips and footrests are essential. Special tools and extractors must be provided to permit easy breakdown and assembly of components.

*Flight Characteristics*

Even if it is not difficult, the helicopter is not easy to fly. Delicacy is required in the co-ordination of controls and there is a lack of uniformity in sensitiveness and feel. Unstable characteristics, and lack of adequate trimming means add to the difficulties associated with night and blind flying, and encourage mental and physical fatigue. Positioning of controls, and their relationship to normal movements of the body; cockpit comfort in terms of seating visibility and temperatures; and selection of grouping and readability of instruments all require careful investigation. To facilitate operation from confined areas and increase safety, rapid rate of climb with steep angle of ascent during take-off is imperative. The rate of descent in auto-rotation must be slow at low translational speed. In fact, the whole psychological aspect of helicopter piloting needs exploring.

*Operation*

Essential requirements are that the equipment used shall be reliable and safe. To achieve maximum utilisation and reduce maintenance time and costs all components should have a " stated life." Safety on the ground to crews and spectators must be assured by adequate elevation of the blade tips of the main torque compensating rotors. Safety in flight entails a means to neutralise external effect of rain on, and internal misting of, transparent nose portion. For passenger work the

fuselage must be roomy and easy of access, with vibrational and sound levels of a low order. The comfort of the seats, positioning to give good external view, and adequate provision for luggage are important. Present economics of helicopter operation preclude other than specialised uses because of the initial cost and limited payload capacity. Although mail and freight capacity might easily be improved, passenger accommodation presents a different problem. For operation in and out of densely populated areas, routes where a water crossing is involved, and operation over mountainous terrain, twin-engine installation appears obligatory. The ability to fly blind and by night considerably enhances utilisation, and assists in reducing the economics of operation to a reasonable level. Basic requirement from the industry is the production of an acceptable product at an acceptable price, and to this end close liaison between constructor and operator must be established during the design stage. On completion of prototype trials aircraft should be handed over to an experienced operator for accelerated development to a satisfactory operation standard.

**The Technical Problems of the Civil Helicopter by Capt. R. N. Liptrot, C.B.E., B.A.**

The existing helicopters are criticised and the following problems, which stand out for investigation during the next development stage, are discussed.

1. *Vibration*

It is obvious that in the helicopter in forward flight we have a dissymmetry of lift which must be corrected and, therefore, a serious vibration problem, since the aerodynamic loads on the blade system are fluctuating.

The classic solution, the flapping blade introduced by Don Juan de la Cierva, is elegant in automatically correcting for the dissymmetry of lift on the advancing and retreating blades, and relieving the blade roots of the periodic bending moments, but, while it has given us the first practical helicopters, it has only accentuated the vibration problem. This is due to Coriolis forces and the further dissymmetry due to the tilting of the tip path plane, which is the result of flapping. Tilting the tip path plane, and so the thrust in order to obtain a forward component force for translation, also causes vibration due to periodic tip stalling. Vibration rather than compressibility effects may, in fact, be the major factor in limiting the speed of helicopters.

2. *Simplification of Control*

Existing helicopters are difficult to fly, at any rate initially, for experienced fixed-wing pilots, because they have to learn that flight at low or even zero air speed is a normal manœuvre for the helicopter, whereas loss of air speed on a conventional aeroplane can be catastrophic. Moreover there are difficulties in the helicopter because of the need to co-ordinate an additional control—the collective pitch—and the response characteristics of the powerful control which is available. A plea is put forward for simplification of controls and modification of control characteristics in order to relieve the pilot of fatigue.

3. *Stability*

With the increasing use of the helicopter, we must expect to have to cater for more and more adverse weather conditions in order to maintain schedules, and so forth. Existing helicopters have poor stability characteristics and blind flying is extremely fatiguing. It is important that the designer gives us improved stability under all conditions of flight.

4. *Safety*

The helicopter, like the autogyro, is essentially safe, since it cannot be stalled in the ordinary sense of the term. In the event of engine failure it is converted to operate in the autogyro state by reduction of pitch, and it can then effect a forced landing exactly as does the autogyro. In present-day types the pilot has to reduce pitch immediately on engine failure, since the rotor would quickly slow down below the safety level. This change to autogyro state would be automatic.

Moreover, there is the difference that the flow patterns are different and that it takes time to establish the autogyro pattern and to gain the necessary air speed for

a satisfactory approach, a height loss of some 300 ft. being involved if engine failure occurs when hovering. This is a potential hazard which must be removed.

5. *Maintenance*

The major factor to-day in the economics of helicopter operation is the maintenance cost due to direct labour in short period overhaul and inspection, the excessive requirements of replacement parts, and the time lost because of unserviceability. All parts must be designed to give long life, periods between inspections must be lengthened, rotor hubs and controls must be simplified with the minimum of moving parts, and all bearings must be adequate. Mention is made of the problem of friction oxidation (the so-called " False Brinnelling ") which occurs in oscillating bearings operating over a small angular range. Engine installations in particular are bad in early helicopters, and servicing of plugs and accessories in some cases is virtually impossible.

AFTERNOON SESSION

**The Fairey Gyrodyne by J. A. J. Bennett, D.Sc., M.A., D.I.C., F.R.Ae.S., F.Inst.P.**

1. *General Features*

The Gyrodyne is designed primarily for safe transport at a cruising speed high enough to ensure continuity of operation under adverse wind conditions. The Gyrodyne principle—of using a single rotor in torque balance with a single propulsive airscrew—results in a greater margin of safety for the main transmission, because the proportion of power delivered to the rotor decreases with increase in forward speed. Low-pitch operation under all conditions of flight and a relatively low disc loading are basic features of the present machine which enhance its safety.

The " bugaboo " of rotary wing aircraft—vibration—is minimised in the Gyrodyne by rotor blades of accentuated flexibility in bending but rigid in torsion, by the avoidance of torsional bearings, by inclined flapping hinges which cause the blades to feather as they flap, by a tilting-head control system which allows the tip-path plane to remain nearly perpendicular to the hub axis in all conditions of steady flight, by hydraulic dampers which effectively govern the drag hinge motion with relatively little restraint, and by the level attitude of the tip-path plane in the normal operating condition of flight—an attitude in which the relative air speed has substantially no down-flow component, thereby ensuring that the associated periodic blade-tip stalling is avoided.

2. *Special Features*

Stick shake is completely eliminated by the use of hydraulic irreversibility, although the initial few hours of flight were performed with controls reversible, not only in regard to blade torsional moments, but in regard also to any moment tending to tilt the rotor head. Thus a measure was obtained of the combined loads which the hub experienced in flight, and not until the resulting control loads were found to be small in magnitude was hydraulic irreversibility introduced.

Control simplification has been achieved by the elimination of a collective pitch control. Collective pitch change is effected automatically about the flapping and drag articulations and there are no flight controls other than stick, throttle and foot pedals. The automatic change in blade angle is associated with the angular displacement of the blade in azimuth in response to torque. There is an immediate increase in manifold pressure whenever the throttle is opened without there being any appreciable change in angular speed. The blade articulations, therefore, self-govern the collective pitch quite independently of any over-riding collective pitch control that may eventually be provided for other purposes. An alternative hub arrangement has been designed incorporating such an over-riding control, mainly for trim purposes at altitude.

3. *Performance*

The flight trials of the two prototypes have been conducted at a gross weight equal to that of the production aircraft, which, including pilot, three passengers, 150 lb. of luggage and 50 gallons of fuel, is approximately 4,800 lb. At this gross weight the

Gyrodyne differs little in vertical performance from the best existing helicopter, but in regard to climb (at the best climbing speed) and in regard to maximum speed in level flight, the Gyrodyne appears in both respects to be markedly superior to present helicopters. This improvement in performance is effected without appreciable departure from the low disc-loading and low-pitch advantages which contributed basically to the remarkable record of safety achieved by rotary-wing aircraft in the pre-war era. The highest recorded speed of the first prototype is 124.3 m.p.h. (an F.A.I. record for helicopters).

**The Bristol 171 Helicopter by R. Hafner**

The problems raised in the morning session are discussed and the approach adopted in the design of the Bristol helicopter is analysed.

1. *Vibration*

Vibration is a fundamental symptom in rotating wing flight which cannot be eliminated but only reduced to generally acceptable proportions. A more accurate definition of vibration level is suggested and the necessity of an agreement regarding threshold of comfort is pointed out. Mainly responsible for vibrations are forces of a cyclic nature acting on the rotor, which arise because conventional rotor control mechanisms can only accommodate a simple sinoidal incidence variation during revolution, whereas the function for blade feathering is rather complex involving an infinite Fourier's series. Means of suppressing the higher terms of blade feathering are indicated.

The envelope of flight conditions of the rotor for the Bristol 171 helicopter is analysed and it is shown how rotor vibration at high forward speed can be avoided. Methods of reducing stresses in the blades due to forces in the plane of rotation are indicated.

2. *Controls*

A simple rotor control is desirable, but there are fundamental limitations to simplifications, which it is contended have already been reached in the present day designs. There is still room for improvement in the detail design of these controls and particularly in the layout of controls in the pilot's cockpit. Standardisation of cockpit controls is an urgent need.

3. *Stability*

We are far from a real solution of this problem. From the flying point of view distinction should be made between hovering stability and stability in forward flight, as the first applies to landing and take-off only, whereas the second applies throughout the flight. Apart from this the two types of stability are based on different principles and can therefore be obtained by different means.

4. *Capital and Maintenance Costs*

The high purchase cost of the present day helicopter is entirely due to the limited production of to-day. Maintenance cost can be materially reduced if attention is paid to the following design principles:—

(*a*) Mechanical simplicity and economy in the number of moving parts.
(*b*) Fatigue resistance and longevity (high life factors) of parts which are subject to wear.
(*c*) Accessibility.
(*d*) Interchangeability.

It is shown that design of the Bristol helicopter has to a large extent been governed by these principles. The number of mechanical parts in the rotor control has been reduced to almost a theoretical minimum. The fatigue properties of the components have been tested extensively by special testing gear. The design life of all wearing parts, with the exception of items such as tyres, is 7,500 hours. It is hoped thereby that the periods between major inspections (excepting the power unit) will be between 1,000 and 2,000 hours.

**The Cierva Air Horse, by J. S. Shapiro, Dipl.Ing., A.F.R.Ae.S.**

*A. Description, Origin, Distinguishing Features*

The conception is a natural one and can be traced to early origins (Barclay 1903, Florin 1921). Novelty consists in balance and control system, characterised by flapping blades, torque re-action through tangential thrust components control by common and differential collective pitch variations of 3-rotors combined with differential cyclic control for directional couples, long travel undercarriage. Development features include:—

(*a*) Use of common cyclic control for suppression of flapping.
(*b*) Directional trim by means of orientable fins.
(*c*) Variable longitudinal dihedral by differential cyclic control.
(*d*) Inter-linkage of common collective and directional controls.

*B. Claims and Criticisms*

Configuration has many advantages, some of which are listed with comments:—
(*a*) Powerful control in roll and pitch.
(*b*) Control in roll and pitch independent of total lift.
(*c*) Little interference of controls.
(*d*) Static stability over whole range of forward flight.
(*e*) Dynamic stability in hovering and forward flight.
(*f*) Favourable vibration characteristics.
(*g*) Maximum U/C track and wheel base leading to ground stability.
(*h*) Ideal entry and stowing layout through rear access and free fuselage cross-section.
(*i*) Small weight penalty for high energy absorption undercarriage.
(*j*) Lack of sudden disturbance due to lateral blade flapping.
(*k*) Accessibility of engine and gearboxes.
(*l*) Insensitivity to fully loaded c.g. position.

As possible criticisms it is natural to consider complication, weight and performance.

*C. Approach*

To evaluate this machine, an approach is chosen from the standpoint of the professional operator, employing skilled personnel. The distinction is fundamental and implies unity of conception summarised as " low cost in terms of pence per ton mile or passenger mile at speed leaving substantial margin compared with surface transport, accompanied by highest possible safety." While " transport " is here considered basic operation, other duties (" crane ") can be reduced to equivalent criteria. Viewed thus, complication is not an independent criterion, but merely insofar as it affects servicing expenditure.

It is emphasised that the private flying approach is fundamentally different.

With " economic " approach in mind, evaluation of the Air Horse can be formulated in essentials:—

(1) Are advantages of 3-rotor machines accompanied by weight and drag penalty?
(2) Can weight and cost of long travel undercarriage be justified?

*D. Evaluation* (with reference to twin-engined civil version)

(1) Performance of helicopters, in terms of low cost operation, like that of other aircraft, is determined by four factors:—

(*a*) Size. (*b*) Configuration. (*c*) Choice of parameters. (*d*) Detail design.

In the range of present day helicopters, *size* has decisive effect. Three-rotor machine possesses cardinal merit of allowing optimal size without danger or rotor limitations set by flapping blades.

*Configurations* are as yet difficult to compare, but a comparison can be made between similar configurations having different numbers of rotors and outriggers. This shows optimum number of rotors to be four, but gain over three is small and such 4-rotor configuration would have few advantages, and some disadvantages over 3-rotors. The comparison is realistic down to side by side twin-rotor machines,

but breaks down for both single-rotor and tandem configurations. While advantage of 3-rotor over both is less than shown, it can at least be safely confirmed that 3-rotor configuration enjoys its numerous advantages without special weight penalty. Drag penalty is outweighed by boom lift.

*Choice of Parameters* is sometimes a neglected art and therefore details are given in graphs showing influence of basic design parameters on economics for machines of given power. Three-rotor facilitates simultaneous fulfilment of optimum conditions for " crane " and " transport " operation.

*Detail Design,* reflects experience and technical standard of designer and his team. General principles unaffected by configuration but novel configuration presents new difficulties and new opportunities. Large size helps efficiency of detail. Unity of purpose helps balance conflicting requirements.

(2) Long-travel undercarriage weight penalty is small in itself. (Mainly structural.) Fully justified by:—

(*a*) Safety independent of pilot's skill.

(*b*) No danger zone in vertical flight, simplifies take-off, landing techniques and facilities, shortens block time, enhances regularity.

(*c*) Optimum blade angle operation at take-off with optimum solidity blades increasing payload by margin approaching U/C excess weight.

*E. General Comments*

Detail requests expressed by operators can be classified into the following categories:—

(*a*) Those automatically fulfilled in the Air Horse due to configuration or size.

(*b*) Those arising from lack of foresight. (Many vibration troubles included.)

(*c*) Conflicting requirements. Call for quantitative information. Example: Value of lb. weight per hour maintenance.

(*d*) Those calling for research. Include some vibration aspects (but not all), simplification of control improvement of basic elements such as articulation.

*F. Conclusion and Further Development of " Air Horse "*

Attainable performance and economics, future possibilities. Vision of large scale utilisation.

*G. Concluding Remarks*

(*a*) Importance of early attention to operational techniques, and facilities.

(*b*) Influence of regulations on design and operation sides.

## AERODYNAMICS AND FLUID MECHANICS

A general course in Aerodynamics and Fluid Mechanics will be held at the College of Aeronautics from 22nd to 25th November 1948 inclusive. Copies of the Syllabus and Registration forms may be obtained from the Registrar, College of Aeronautics, Cranfield, Bletchley, Bucks.

## LECTURE PROGRAMME—AUTUMN SESSION 1948

Unless otherwise stated, lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, London, S.W.1 (by permission of the Council of the Institution). Tea will be served at 5.30 p.m.

**Thursday, 21st October 1948**

Cold Weather Operation of Aircraft, by G. W. Wilson, A.F.R.Ae.S., M.I.Ae.S., and Squadron Leader E. P. Bridgland, R.C.A.F., B.Sc., A.F.R.Ae.S., A.F.I.Ae.S.

**Thursday, 28th October 1948**

Aircraft Engineering and Production, by a Member of the Staff of Handley Page Ltd.

**Thursday, 11th November 1948**

French Aircraft Gas Turbines, by M. Destival.

**Saturday, 20th November 1948**

FULL DAY DISCUSSION ON HELICOPTERS

(A Joint Meeting with the Helicopter Association)

*Morning Session*

11 a.m. to 1 p.m.—GENERAL PROBLEMS OF THE HELICOPTER FOR CIVIL USE.

11 a.m.—The Operational Point of View, by W/Cdr. R. A. C. Brie, A.F.R.Ae.S., A.F.I.Ae.S.

11.30 a.m.—The Technical Point of View, by Capt. R. N. Liptrot, C.B.E.

12 noon.—Discussion.

1 p.m. to 2.30 p.m.—Luncheon Interval (Members should make their own arrangements).

*Afternoon Session*

2.30 p.m. to 4.30 p.m.—THE CONSTRUCTORS' APPROACH TO THE PROBLEMS.

2.30 p.m.—The Fairey Gyrodyne, by J. A. J. Bennett, D.Sc., M.A., D.I.C., F.R.Ae.S., F.Inst.P.

3.0 p.m.—The Bristol 171 Helicopter, by R. Hafner.

3.30 p.m.—The Cierva Air Horse, by J. S. Shapiro, Dipl.Ing., A.F.R.Ae.S.

4.0 p.m.—Discussion.

4.30 p.m. to 5 p.m.—Tea Interval. (Tea will be provided at the Lecture Hall.)

*Evening Session*

5 p.m. to 6.30 p.m.—General Discussion and summing up by the Lecturers and the Chairman.

**Thursday, 25th November 1948**

Development of the Armstrong Siddeley Mamba Engine, by W. H. Lindsey, M.A., A.F.R.Ae.S.

**Thursday, 2nd December 1948**

Problems in the Development of a New Aeroplane, by G. R. Edwards, M.B.E., B.Sc., F.R.Ae.S.

**Thursday, 16th December 1948**

Present Thoughts on the Use of Power Flying Controls in Aircraft, by D. J. Lyons.

## GRADUATES' AND STUDENTS' SECTION—LECTURES

**Tuesday, 26th October 1948**—Flight Refuelling, by Sir Alan J. Cobham, K.B.E., A.F.C., Hon.F.R.Ae.S., Managing Director, Flight Refuelling Ltd.

**Wednesday, 10th November 1948**—Flying Experiences, by Lt. Cdr. (A) E. M. Brown, R.N., O.B.E., D.S.C., A.F.C., M.A., A.R.Ae.S., Chief Naval Test Pilot.

**Wednesday, 24th November 1948**—The Investigation of Aircraft Accidents, by Air Cdre. Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S., Chief Inspector of Accidents, Ministry of Civil Aviation.

**Tuesday, 7th December 1948**—Papers read by members of the Graduates' and Students' Section.

**Tuesday, 21st December 1948**—Production, The Dynamics of People at Work, by J. V. Connolly, B.E., A.F.R.Ae.S., Professor of Aircraft Economics and Production at the College of Aeronautics.

Meetings will be held in the Library of the Royal Aeronautical Society, 4 Hamilton Place, W.1, at 7.30 p.m. *The Library will not be open before 7 p.m.*

## BRANCH NOTICES

BIRMINGHAM BRANCH

**Monday, 8th November 1948**—Aircraft Armament by S. J. Millars, Boulton Paul Ltd.

At the Birmingham Chamber of Commerce at 7.30 p.m.

COVENTRY BRANCH

**Thursday, 21st October 1948**—Development of the Brabazon I, by G. P. Hebden, Bristol Aeroplane Co. Ltd.

**Thursday, 18th November 1948**—Electronics, by Dr. Whiteley, British Thomson-Houston Ltd.

**Thursday, 9th December 1948**—Lecture by E. Smith, Research Department, Firth-Vickers Ltd.

All lectures will be held in the Old Gulson Library, Coventry, at 7.30 p.m.

GLASGOW BRANCH

**Thursday, 28th October 1948**—Lecture by a Branch Member, at 7.30 p.m., at The Grand Hotel, Charing Cross, Glasgow.

**Tuesday, 30th November 1948**—" Lecturettes," at 7.30 p.m., at Prestwick Airport.

**Thursday, 23rd December 1948**—Annual General Meeting, at The Grand Hotel, Charing Cross, Glasgow.

GLOUCESTER AND CHELTENHAM BRANCH

**Thursday, 18th November 1948**—Problems Facing Civil Air Operations, by N. E. Rowe, C.B.E., F.R.Ae.S.

At the Wheatstone Hall, City Library, Brunswick Road, Gloucester, at 7.30 p.m.

HATFIELD BRANCH

**Wednesday, 17th November 1948**—Design Problems of Large Flying Boats, by H. Knowler, F.R.Ae.S.

At 6.15 p.m. in the de Havilland Senior Staff Mess.

ISLE OF WIGHT BRANCH

**Friday, 15th October 1948**—Inaugural Dinner.

**Thursday, 11th November 1948**—" Lecturettes "—Four short talks by members of the production staff of Saunders-Roe, Ltd.

**Thursday, 2nd December 1948**—The Development of the Armstrong Siddeley " Mamba " Engine, by W. H. Lindsey, M.A., A.F.R.Ae.S.

**Thursday, 16th December 1948**—Annual General Meeting and Film Show.

Meetings will be held in the Sports and Social Club, Saunders-Roe, Ltd., East Cowes, Isle of Wight, at 6 p.m.

LUTON BRANCH

**Wednesday, 20th October 1948**—Presidential Address by the Branch President, P. Ll. Hunting, Comp.R.Ae.S., and Discussion Evening.

**Wednesday, 3rd November 1948**—Materials of Aircraft Construction and Material Processing, by Dr. Sutton.

**Wednesday, 1st December 1948**—The Light Aeroplane and the Future of Private Flying, by P. G. Masefield, M.A., F.R.Ae.S.

Meetings will be held generally at The George Hotel, Luton, at 7 p.m.

PRESTON BRANCH

**Wednesday, 27th October 1948**—Design Problems of Large Flying Boats, by H. Knowler, F.R.Ae.S.

**Wednesday, 17th November 1948**—On the Investigation of Aircraft Accidents, by Air Commodore Vernon Brown, C.B., O.B.E., F.R.Ae.S.

**Wednesday, 8th December 1948**—Gusts, by Professor A. A. Hall, M.Sc., M.A., F.R.Ae.S

All Lectures will be held in the Assembly Hall of the Technical College, Corporation Street, Preston, at 7.15 p.m.

PORTSMOUTH BRANCH

**Friday, 22nd October 1948**—Lighter-than-Air Craft, by Lord Ventry, Companion R.Ae.S.

**Friday, 26th November 1948**—Model Section Display.

**Friday, 3rd December 1948**—Films showing " How an Aeroplane Flies."
**Friday, 17th December 1948**—Some Aspects of Carrier Operation, by Capt (E) B. H. Cronk, D.S.C., R.N.(Retd.).

All lectures will be held in the Lecture Hall at the Central Library, Guildhall Square, Portsmouth, at 7 p.m.

WEYBRIDGE BRANCH

**Wednesday, 6th October 1948**—Rocket Propulsion and Inter-Planetary Flight, by A. V. Cleaver, A.R.Ae.S., de Havilland Engines Co. Ltd.
**Wednesday, 27th October 1948**—High Speed Wind Tunnels, by E. J. Richards, M.A., B.Sc., A.F.R.Ae.S. and E. Smyth, B.Sc., A.F.R.Ae.S., Vickers-Armstrongs Ltd. (Weybridge).
**Wednesday, 17th November 1948**—Some Aspects of Practical Flying, by J. K. Quill, O.B.E., Vickers-Armstrongs Ltd. (Supermarine).
**Wednesday, 1st December 1948**—The Island Campaign (Coloured film), shown by W. Courtenay, M.M., A.R.Ae.S., *Daily Graphic* Aeronautical Correspondent.
**Wednesday, 15th December 1948**—Annual General Meeting, followed by films of Vickers Aircraft.

Meetings will be held at Vickers-Armstrongs, Ltd., Weybridge Works, at 6 p.m., unless previous notice is given.

## CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the* **15***th of the month* in order to be effective for the Journal for the following month.

## NEW MEMBERS

*Associate Fellows*

Trevor Ronald Ashcroft (from Graduate), Edward George Bowen, Peter Wright Brooks (from Companion), John Bryce (from Graduate), William Devon Doble (from Graduate), Louis Maurice Gardiner (from Graduate), Thomas Anthony Gawade, Garth Owen Jones, George Victor Richard Jones (from Associate), Stefan Josef Krukowski, John Francis Lewis, Robert B. Meyersburg, Erik Blyth Nelson (from Associate), Laurence Henry Gordon Sterne, Maurice Albert Taunton (from Graduate), Vivian Victor Wilson Vallance, Percival John Waite, Paul Howard Wilkinson, William Manton Willey.

*Associates*

Henry Rossbottom Bairsto, Ronald Edward Bird (from Student), Eric Hider Bowers, Arthur Charles Bridge, Charles Carson Brodie, Mudumbai Narasimha Chari, William Kenneth Crow, Selwyn Howard Evans, Kenneth Walter Booth Fouweather, John Eric Heald, Norman Frederick Hildyard, Adi Murzban Irani, Albert Frederick Jones, James Caldwell Hole Kortright, Raymond Lawrance, Peter Godfrey Lawrence, Reginald William Clifford Mills, Walter Ian Scott-Hill, Eric Roy Sisson, Briercliffe Bleackley Smylie, Alec George Sollis, Alfred George Leslie Standley, Freeman Jesse Steel, John William White, Stuart Edward White.

*Graduates*

John Michael Bennett (from Student), Robert James Martin Beverly, Franck John Maurice Bonnères (from Student), Benjamin Joseph Prior, John Charles Rendle, Robert Alexander Vair.

*Students*

Richard Douglas Archer, Denys Ingraham McCullough, Eileen Muriel Neill, Ronald Eugene O'Donnell, William Alan Pollard, George Lancaster Ronson, Robert Francis Henry Woodberry, George Reginald Wrixon.

*Companions*

Robert Nelson.

## ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

B.a.384—New Book of Flight. C. H. Gibbs-Smith (Ed.). Oxford University Press. 1948.

B.c.77—Experimentelle Untersuchungen uber den Segelflug. P. Idrac. R. Oldenbourg, Berlin. 1932.

*B.g.155—Jane's All the World's Aircraft 1948. L. Bridgman (Ed.). Sampson Low. 1948.

D.a.H.10—La Aeronautica Nacional al Servicio del Pais. Secretaria de Aeronautica de la Nacion Republica Argentina. 1948.

D.b.277—Highways of the Air. V. E. Mearles. Mason. 1948.

EE.h.36—Principles of Jet Propulsion. M. J. Zucrow. Wiley, New York. 1948.

G.a.82—Design of Metal Cutting Tools. F. L. Woodcock. McGraw Hill. 1948.

G.c.32—Mechanical Testing of Metals and Alloys. P. Field Foster. Pitman. 1948.

G.e.E.67—Molybdenum: Steels, Irons, Alloys. R. S. Archer, J. Z. Briggs and C. M. Loeb. Climax Molybdenum Co. of Europe Ltd. 1947.

G.e.J.31—Symposium on Internal Stresses in Metals and Alloys. Institute of Metals. 1948.

K.c.33—Ballistics of the Future. J. M. J. Kooy and J. Uytenbogaart. McGraw Hill. 1946.

L.c.32—Airline Piloting. Raymond Bullock. Mitre Press. 1947.

L.d.123—*Notices to Airmen. Nos.* 288-291, 293, 295-297, 299-308, 310, 311, 313, 321, 323, 324.

M.c.81—Radar Beacons. Arthur Roberts. McGraw Hill. 1947.

OO.123—Proceedings of the National Electronics Conference. Chicago. 1947.

*Q.a.189—Aeronautical Catalogues—1913-1934.

*R.b.263—Extracts on Ballooning and Flight. R. Kronfeld.

S.e.143—Serving a Nation at War. 1939-1945. John Laing & Sons, Ltd. 1946.

### A.R.C. Reports and Memoranda

2119—*The cause of the spontaneous opening and closing of parachutes. (The phenomena of "Squidding.") W. J. Duncan.*

2198—*A note on the toxic effects of some chemicals previously recommended for use in wind-tunnel technique and on vapour and gas explosion risks in wind tunnels. E. R. A. Mercwether, J. H. F. Smith, R. C. Pankhurst and F. H. Burstall.*

2216—*Tests of contra-rotating propellers of $2\frac{7}{8}$ ft. diameter at positive pitch on a "Typhoon" aircraft model. R. C. Pankhurst, J. N. Veasey, J. R. Greening and E. M. Love.*

2219—*Tests on contra-rotating propellers of $2\frac{1}{8}$ ft. diameter at negative pitch on a "Typhoon" aircraft model. R. C. Pankhurst, J. R. Greening and E. M. Love.*

2220—*Tests of contra-rotating propellers, at positive and negative pitch settings, on a "Typhoon" aircraft model at 5 degrees incidence. R. C. Pankhurst, J. N. Veasey, J. R. Greening and E. M. Love.*

2251—*Pressure distribution and wake traverses on models of Mustang wing section in the Royal Aircraft Establishment and National Physical Laboratory high speed tunnels. J. S. Thompson, M. Markowicz, J. A. Beavan and R. G. Fowler. With Addendum: Pressure distribution on a two-dimensional Mustang wing model in the Royal Aircraft Establishment 7 ft. tunnel. J. S. Thompson and W. Port.*

2269—*The choice of loads for ultimate and repeated design and test conditions. P. E. Montagnon and A. Day.*

2270—*Tests of model contra-rotating propellers with a "minimum body." R. C. Pankhurst, J. N. Veasey, J. R. Greening and E. M. Love.*

2279—*The design of minimum drag tip fins. V. M. Falkner. With Appendix: On the conformal transformation of a wing with a fin. Sir Charles Darwin.*

2284—*Fracture of glass rods in bending and under radial pressure. C. Gurney and P. W. Rowe.*

**N.A.C.A. Technical Notes**

1225—*The formation and stability of normal shock waves in channel flows. A. Kantrwoitz.*

1229—*Frequency-response method for determination of dynamic stability characteristics of airplanes with automatic controls. H. Greenberg.*

1445—*Two-dimensional irrotational transonic flows of a compressible fluid. Yung-Huai Kuo.*

1460—*Influence of a crystal plane and surrounding atmosphere on chemical activities of single crystals of metals. A. T. Gwathmey, H. Leidheiser, Jr., and G. Pedro Smith.*

1531—*A metallurgical investigation of five forged gas-turbine discs of timken alloy. J. W. Freeman, E. E. Reynolds and A. E. White.*

1552—*Investigation on the validity of an ideal theory of elasto-plasticity for wrought aluminium alloys. E. G. Thompson, I. Cornet, I. Lotzke and J. E. Dorn.*

1589—*Effect of longitudinal stiffeners on the buckling load of long flat plates under shear. H. Crate and Hsu Lo.*

1591—*Aerodynamic characteristics of a number of modified N.A.C.A. four-digit-series airfoil sections. K. L. Loftin, Jr., and K. S. Cohen.*

1593—*Effects of nacelle position on wing-nacelle interference. C. H. McLellan and J. I. Cangelosi.*

1601—*Characteristics of thin triangular wings with constant-chord full-span control surfaces at supersonic speeds. W. A. Tucker.*

1603—*Application of statistical methods to study of gas-turbine blade failures. C. A. Hoffman and G. Mervin Ault.*

1605—*Accuracy of airspeed measurements and flight calibration procedures. W. B. Huston.*

1613—*A method for determining the aerodynamic characteristics of two- and three-dimensional shapes at hypersonic speeds. H. Reese Ivey, E. B. Klunker and E. N. Bowen.*

1614—*Knocking combustion observed in a spark-ignition engine with simultaneous direct and schlieren high-speed motion pictures and pressure records. G. E. Osterstrom.*

1615—*Investigation of the penetration of an air jet directed perpendicularly to an air stream. E. E. Callaghan and R. S. Ruggeri.*

1616—*Knock-limited performance of several branched paraffins and olefins. R. S. Genco and I. L. Drell.*

1624—*Two-dimensional wind-tunnel investigation of an N.A.C.A. 64-009 airfoil equipped with two types of leading-edge flap. F. F. Fullmer, Jr.*

1626—*A study of ceramic coatings for high-temperature protection of molybdenum. D. G. Moore, L. H. Bolz and W. N. Harrison.*

1627—*Effect of strady rolling on longitudinal and directional stability. W. H. Phillips.*

1629—*The experimental determination of the moments of inertia of airplanes by a simplified compound-pendulum method. W. Gracey.*

1630—*A generalised theoretical investigation of the hydrodynamic pitching moments experienced by v-bottom seaplanes during step-landing impacts and comparisons with experiment. B. Milwitzky.*

1631—*Wind-tunnel investigation of boundary-layer control by suction on N.A.C.A. 655-424 airfoil with double slotted flap. S. F. Raciaz and J. H. Quinn, Jr.*

1633—*An evaluation of the characteristics of a 10 per cent.-thick N.A.C.A. 66-series airfoil section with a special mean-camber line designed to produce a high critical mach number. K. L. Loftin, Jr., and K. S. Cohen.*

1634—*Wind-tunnel tests and analysis of two 10 ft.-diameter six-blade dual-rotating tractor propellers differing in pitch distribution. J. Gilman, Jr.*

1636—*Determination of stresses in gas-turbine discs subjected to plastic flow and creep. M. B. Millenson and S. S. Manson.*

1637—*Effect of pre-ignition on cylinder temperatures, pressures, power output, and piston failures. K. C. Corrington and W. Fisher.*

1638—*Experimental investigation of the jet-boundary constriction correction for a model spanning a closed circular tunnel. M. Tucker and M. D. Rousso.*

1639—*Investigation of some factors affecting comparisons of wind-tunnel and flight measurements of maximum lift coefficients for a fighter-type airplane. D. D. Davis, Jr., and H. H. Sweberg.*

1641—*A method for determination of aromatics in 150 degrees to 300 degrees C. fractions of crude petroleum by measurement of aniline point rise. A. M. Busch, A. P. Cleaves and R. R. Hibbard.*

1642—*Velocity distribution on symmetrical airfoils in closed tunnels by conformal mapping. W. Perl and H. E. Moses.*

1644—*Laminar flow of a slightly viscous incompressible fluid that issues from a slit and passes over a flat plate. Neal Tetervin.*

1645—*A statistical analysis of gust-velocity measurements as affected by pilots and airplanes. Harry Press.*

1646—*Low-speed wind-tunnel investigation of various plain-spoiler configurations for lateral control on a 42 degrees sweptback wing. K. E. Schneiter and J. M. Watson.*

1647—*Sound-level measurements of a light airplane modified to reduce noise reaching the ground. A. W. Vogely.*

1648—*Tank tests of a 1/10 size model of a hypothetical flying boat with a hull length-beam ratio of 9.0. Marvin I. Haar.*

1651—*Supersonic nozzle design. J. C. Crown.*

1652—*Investigation of axial-flow fan and compressor rotors designed for three-dimensional flow. A. Kahane.*

1653—*Charts for the computation of equilibrium composition of chemical reactions in the carbon-hydrogen-oxygen-nitrogen system at temperatures from 2,000 degrees to 5,000 degrees K. V. N. Huff and C. S. Calvert.*

1664—*A device for measuring sonic velocity and compressor mach number. P. W. Huber and A. Kantrowitz.*

**N.A.C.A. Technical Reports**

794—*The flow of a compressible fluid past a circular arc profile. Carl Kaplan.*

The following reports have also been received:—

**C.S.I.R. Division of Aeronautics**

*Report SM* 112.

**Publications Scientifiques et Techniques du Ministere de l'Air**

*Report No.* 217.

J. LAURENCE PRITCHARD,
*Secretary.*

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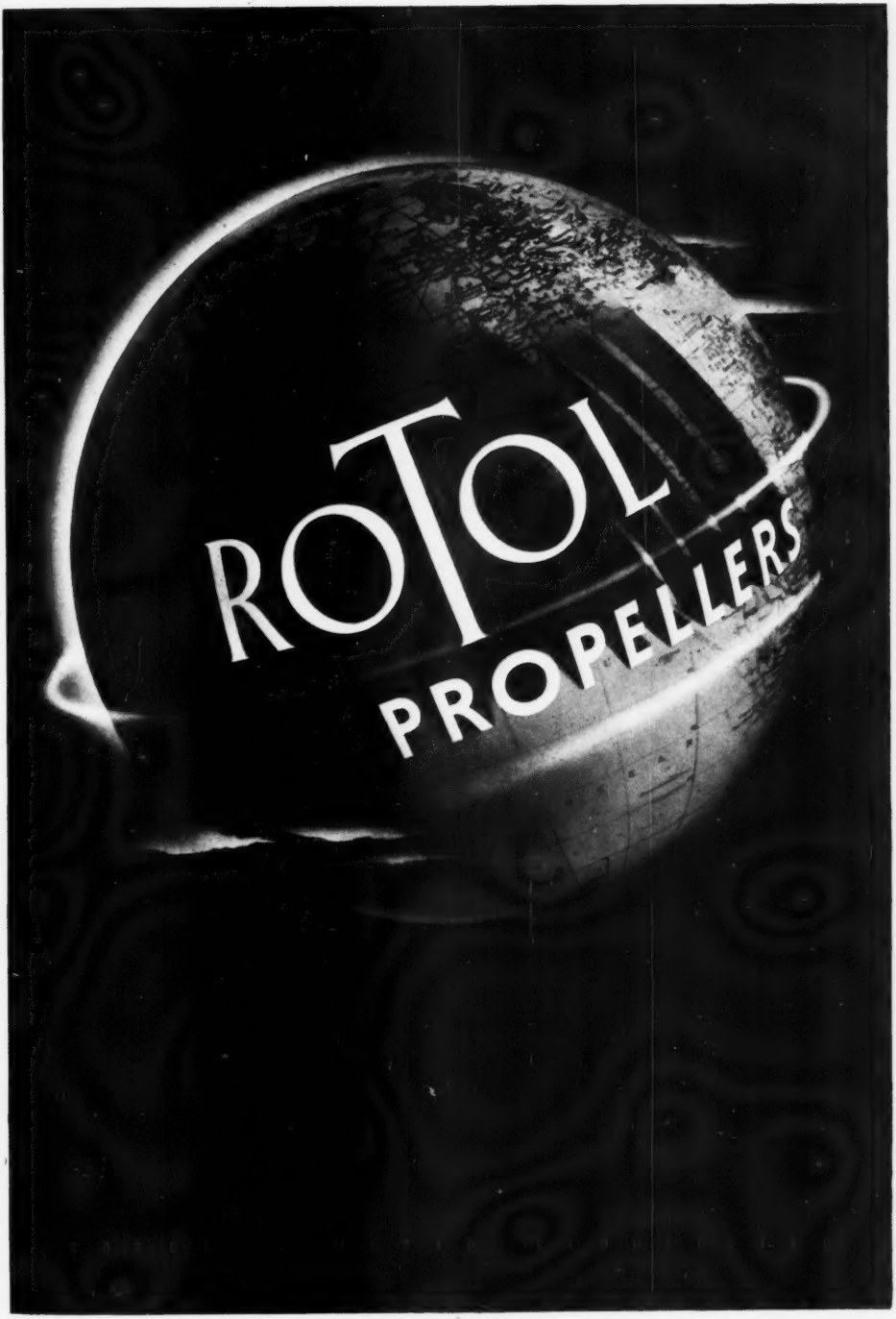
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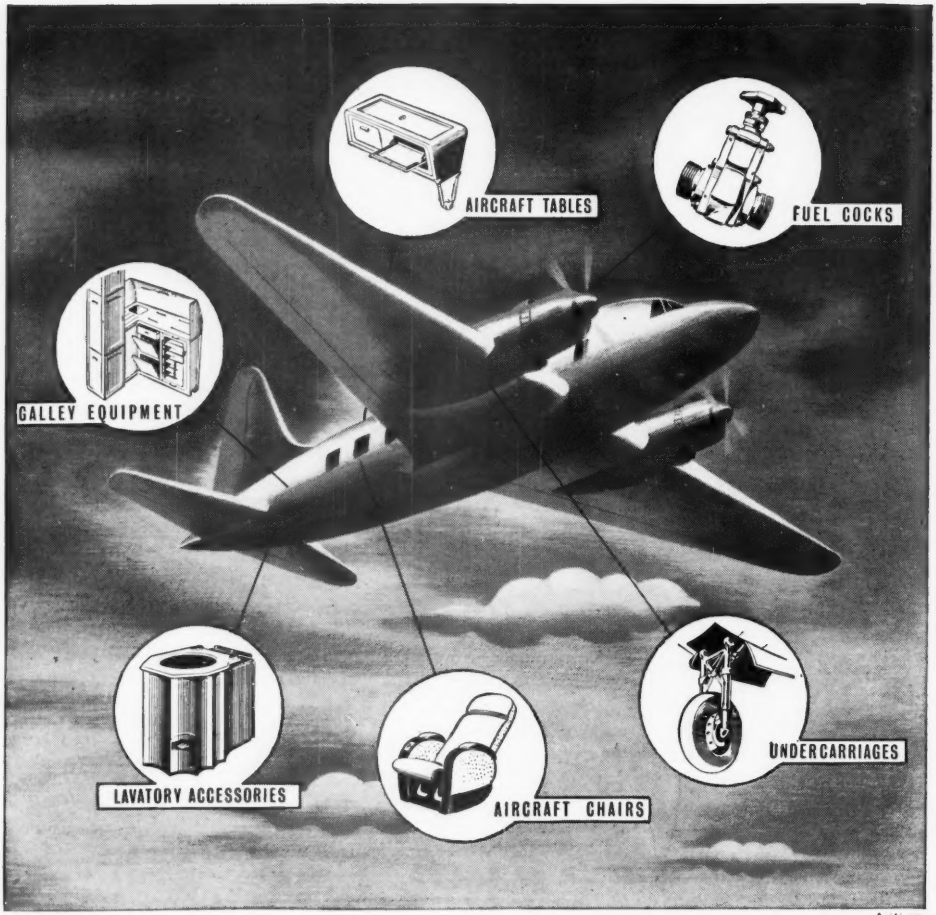


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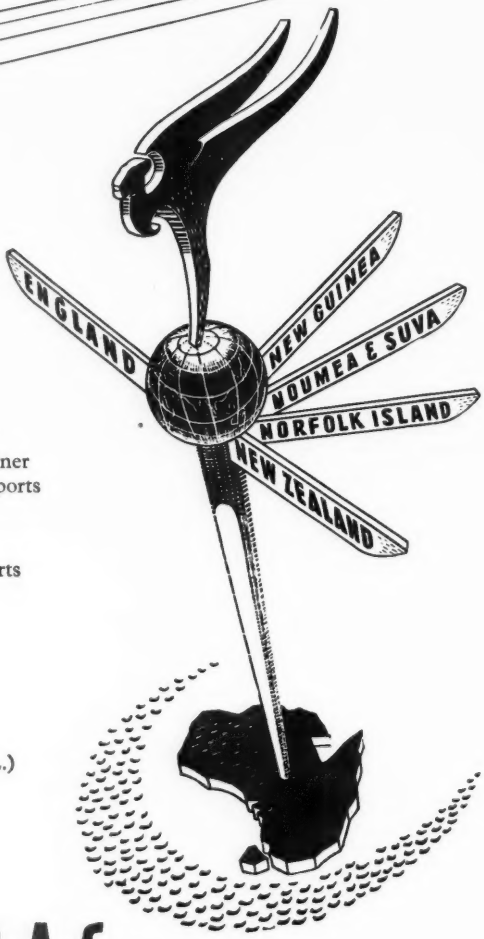


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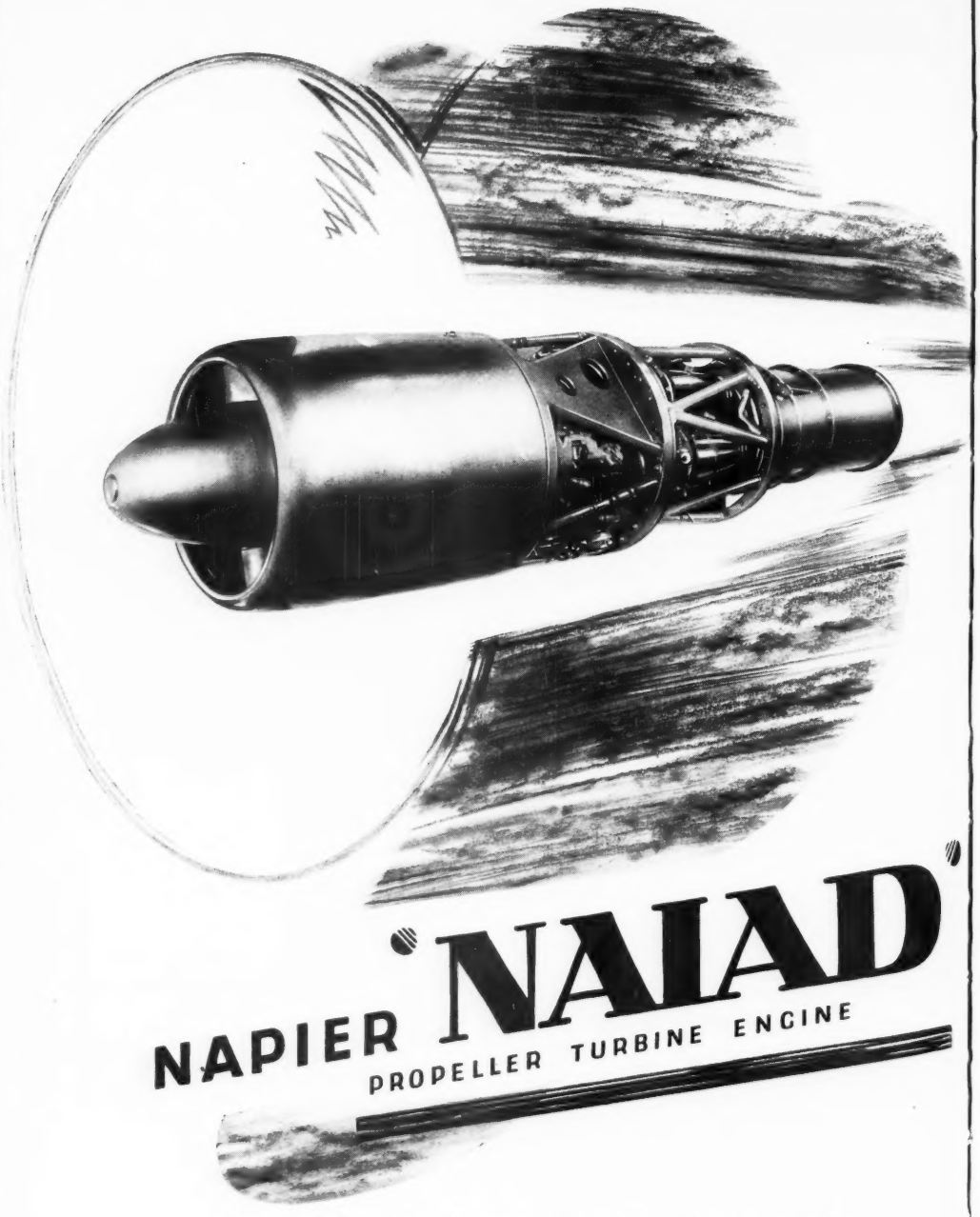


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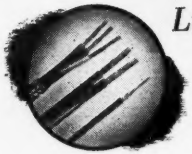

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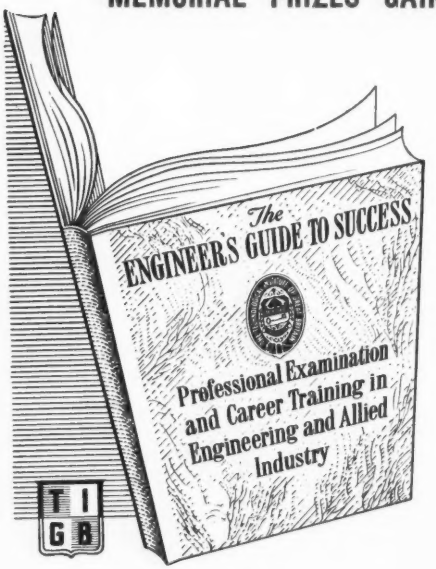


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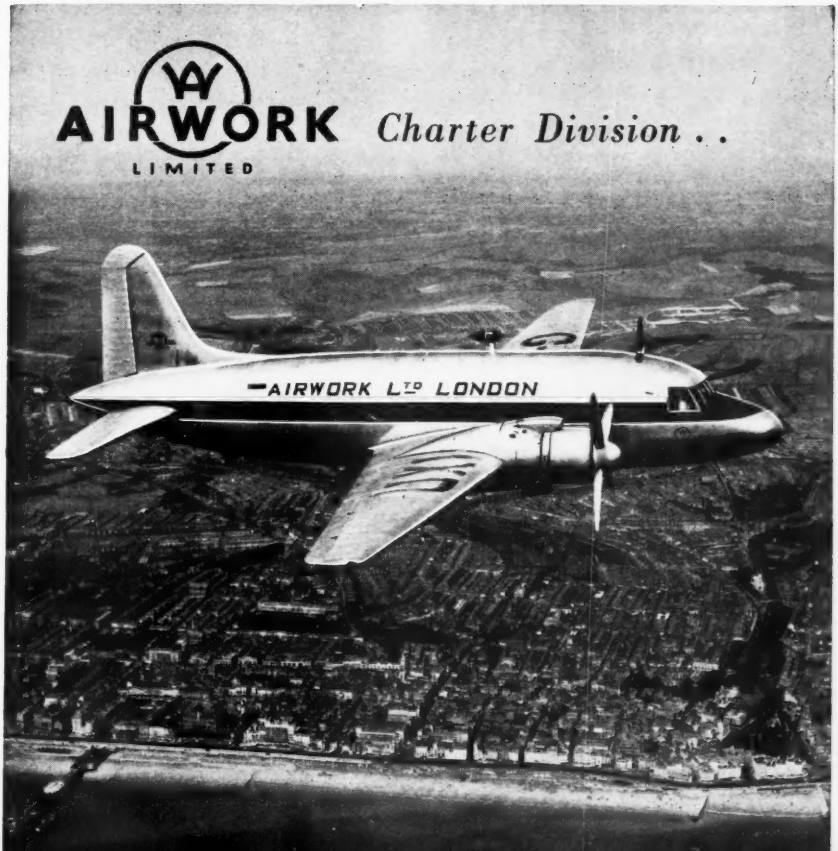


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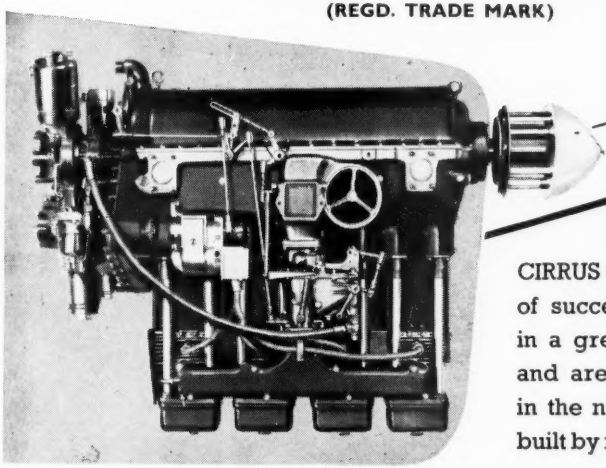

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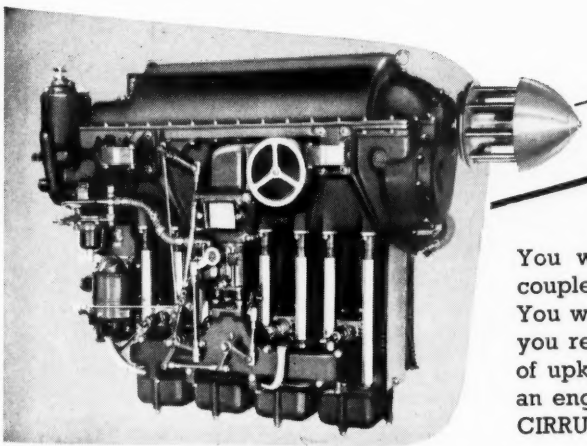

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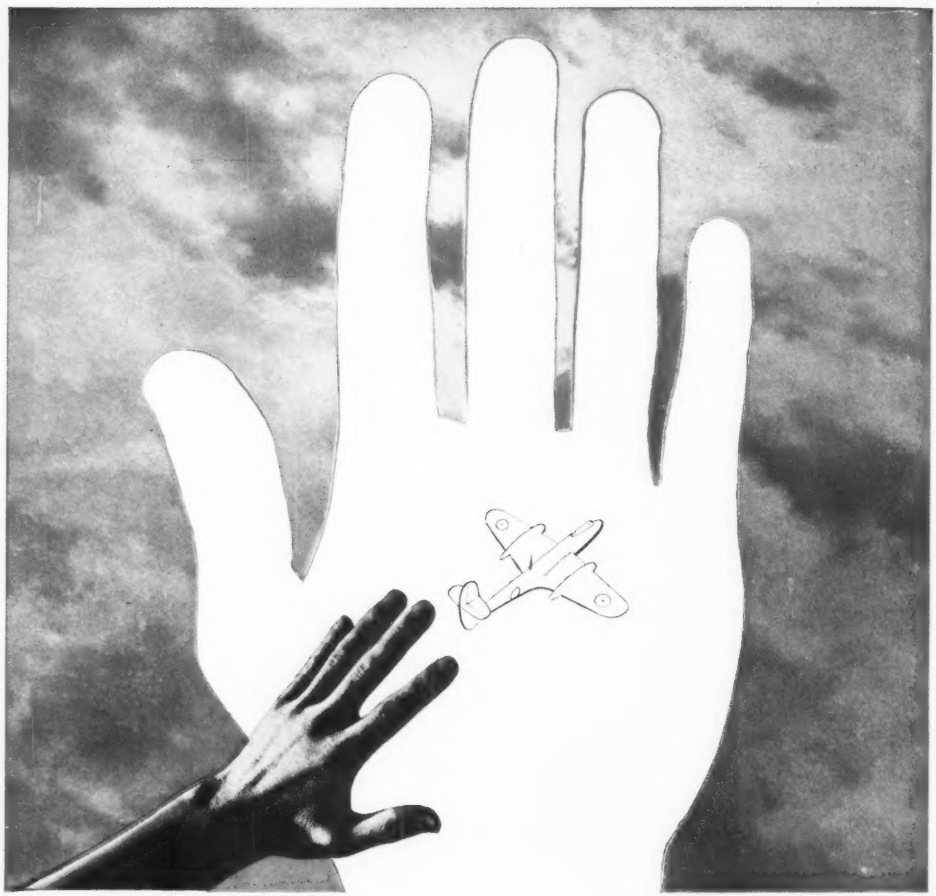

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Awarded for the most valuable paper submitted or read during the previous session.

**Wakefield Gold Medal**

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The British Commonwealth and Empire Lecture is delivered annually by a lecturer chosen in alternate years from the British Dominions and Colonies and Great Britain.

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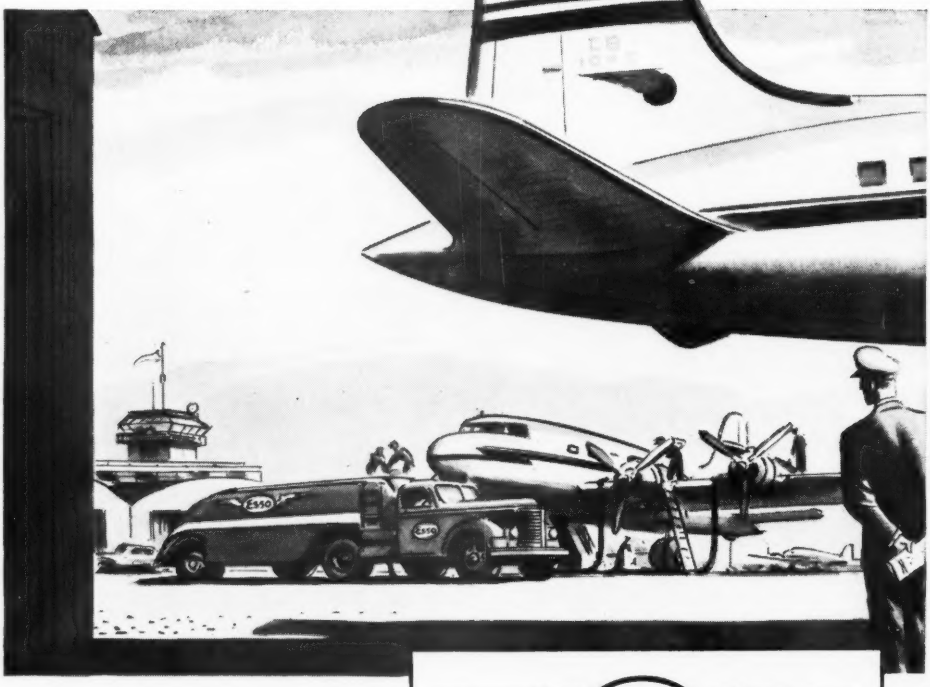


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Papers must be in English, in the third person, and typed on one side of the paper only, with double spacing and wide margins. When submitted they must be in their *final form for publication.* Only typographical errors may be corrected in proofs. Titles of papers should be brief.

Where practicable, a summary of not more than 250 words should be given at the beginning of the paper, giving its scope and conclusions.

All references should be numbered in the text where they occur, and the complete list of references given at the end of the manuscript. These references will be published at the end of the text. Footnotes should be numbered consecutively. Tables should be kept as concise as possible.

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Every drawing and photograph should have on the back its figure number and title.

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Only very simple symbols and formulæ should be typewritten. All others should be written carefully by hand in ink. Ample space for marking should be allowed above and below all equations. Greek letters should be designated by name in the margin.

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All subscripts and exponents should be clearly marked, and dots, bars, and so on, over letters should be avoided as far as possible.

Square roots of complicated expressions should be written with the exponent $\frac{1}{2}$ rather than with the sign $\sqrt{}$.

Complicated exponents and subscripts should be avoided. Any complicated expression that recurs frequently should be represented by a special symbol.

Unless an abbreviation is one recognised as standard practice, both in this and other English-speaking countries, for example, b.h.p. for brake horse power, the meaning should be given in full on its first use.

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# SOME ECONOMIC FACTORS IN CIVIL AVIATION

## With Emphasis on Civil Aircraft and Their Prospective Trends of Development

by

PETER G. MASEFIELD,* M.A., F.R.Ae.S., M.I.Ae.S., G.Inst.Mech.E.

THE FOURTH British Commonwealth and Empire Lecture was given before the Society by Mr. Peter G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., G.Inst.Mech.E., on Thursday, 30th September 1948, at six p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1. The Chair was taken by Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., F.I.Ae.S., President of the Society.

**The President:** There have been in the Commonwealth for many years Branches of the Society, but it has long seemed to the Council desirable that these Branches should achieve, so to speak, Dominion status and after negotiations it has been possible to so modify their Constitutions, at least in two cases, that they are now really Royal Aeronautical Societies on their own. The official position is made clear by this recommendation which was passed by the Council this afternoon:—

> "The President and Council of the Royal Aeronautical Society are convinced that the objects of the Society will be furthered by the establishment of Divisions of the Society within the British Commonwealth and are resolved that such Divisions shall be established."

In pursuance of that resolution it has been possible to bring into being the Royal Aeronautical Society of Australia and the Royal Aeronautical Society of New Zealand. Negotiations are going on with other nations of the Commonwealth and we have confidence that similar Royal Aeronautical Societies will come into being there also. It seemed to me that it was most relevant that at this meeting these highly important developments should be made known.

To-night we open the 1948-49 Lecture Session with the Fourth British Commonwealth and Empire Lecture. This is one of the two major lectures of our year, the other being the Wilbur Wright Lecture with which we conclude our session.

The lecturer this evening is Mr. Peter Masefield, who took his degree in engineering at Cambridge as recently as 1935. After spending two years on the design staff of the Fairey Aviation Company, he joined the staff of *The Aeroplane* where he remained until 1943.

As Air Correspondent from 1940-43 for the *Sunday Times*, commentator on air matters from time to time for the B.B.C. and War Correspondent with the U.S. 8th Air Force, the author obtained a wide experience of aviation.

He was largely responsible for proving the importance of aircraft recognition, and had much to do with the Royal Observer Corps and the Spotters Clubs. From 1943 to 1945 he was Personal Adviser on Civil Aviation to the Lord Privy Seal, Lord Beaverbrook, and he was Secretary of the Cabinet Committee on Post-War Civil Air Transport.

In 1945 the lecturer became the first British Civil Air Attaché in Washington, and joined the Ministry of Civil Aviation the following year as Director-General of Long Term Planning and Projects.

He is a pilot, a Fellow of the Royal Aeronautical Society, and he has been a member of Council since 1945.

---

* Director-General of Long Term Planning and Projects, Ministry of Civil Aviation
(All the opinions expressed in this Paper are the sole responsibility of the author and do not, necessarily, reflect any official viewpoint.)

# INTRODUCTION

LONG-RANGE TRANSPORT is, after the Crown, the most vital and the most significant of all the ties which bind the British Commonwealth and Empire into a community of free peoples. Of all the forms of transport which thus enlace the Commonwealth, Air Transport is at once the swiftest and the most capable of development.

The Australian historian, Paul McGuire, describes the Commonwealth as:—

*"the nearest man has yet approached to achieving a World Community. It offers a framework on which a system of World Order could be built."*

That is the great conception in which Air Transport is privileged to play a dominant part.

For that reason, the annual British Commonwealth and Empire Lecture of the Royal Aeronautical Society has a significance which is wider even than the record of aeronautical progress which it serves to mark each year. I am, thus, very conscious of the honour which the Council has done me by its invitation to deliver the Fourth and 1948 Commonwealth and Empire Lecture. It is both a privilege and a responsibility of which I am deeply appreciative.

I follow three predecessors each of whom has earned a particular niche for himself in the hall of fame of Commonwealth Aviation —Mr. Hudson Fysh, pioneer of Australian Air Transport; Sir Henry Self, doyen of aeronautical civil servants, now short-circuited into Electricity; and Mr. James T. Bain, inspirer of Canadair and in himself an outstanding prototype of Anglo-Canadian aeronautical progression.

I can claim no niche equivalent to these. But as an observer and as a, non-political, participator in some of the policy discussions on the international, the administrative, the operating, the technical, and the manufacturing sides of Civil Aviation during the past few years, and as a wrestler with some of the long-term problems of Civil Aviation in addition, I have at least been able to form views and opinions based on experience which has ranged, albeit superficially, over most of the field.

Each of my predecessors in the Commonwealth and Empire Lecture has surveyed some historical feature of Civil Aviation. In this lecture I shall hope to draw on some of that historical background, which they have provided with such knowledge and experience, and project some of its lessons into the future—that clouded crystal ball into which we all peer so often, so hopefully and, I fear, with frequently so little foresight.

I have chosen as my subject:—

"SOME ECONOMIC FACTORS IN CIVIL AVIATION

*With emphasis on Civil Aircraft and their prospective Trends of Development."*

I have done so because I believe, most sincerely, that operating economics must be the foundation of all our progress in Commercial Aviation. Civil Aviation, to succeed, has to be able to support itself financially in the air. It has not done so yet. But it can and must do so in the future—whatever may be the favoured hues of the ties of those who may decide its policy.

Operating economics are the essence of commercial Air Transport. That fact is my text and my theme.

I have therefore attempted to survey, in its broadest sense, what I believe to be the economic prospects of our aeronautical developments, extracting and underlining, where I can, the fundamentals which go to make up the kaleidoscopic form of this aeronautical complex. In particular I have tried to analyse where the trends of aircraft development may be heading in the immediate future; that is to say, during the next twelve years or so.

I have dealt particularly with aircraft, the standards on which they are operated and their possible future developments, because aircraft are the foundation of the economics of the business. Aircraft are the one stock in trade of the commercial operator. A bad operator can lose money on a good aeroplane. But however good the operator, he can achieve neither profits nor safety from a bad aeroplane. Thus the aeroplane is the essential —it must be suitable for the job in hand. Once efficient aircraft have been provided, then the results lie with the ability of those who run them.

To summarise what follows:—

The procedure I have pursued in setting out this Paper is:—

First, to set the scene by analysing the purpose which Air Transport should attempt to serve.

Second, to establish the background by examining the present status of Air Transport and its economic position.

Third, to consider its commercial confines by setting out the operating standards on which scheduled services have to be built.

Fourth, to measure the progress made so far by assessing the trends of performance and economics achievable with present types of aircraft throughout the range of sizes (with examples from the Rapide up to the Brabazon I).

Fifth, to project these present achievements forward into the future in relation to potential new types of aircraft and power plants, and

Finally, to sum up these prospects in relation to the purpose of Air Transport, especially in terms of the service it can offer to mankind.

The canvas is large and the complexities are great. A lifetime of study and experience would be too little in which to draw out from so wide and so swiftly developing a subject the full measure of what it has to offer to the World.

In shouldering so heavy a task, I trust that I may at least have succeeded in focusing a perspective on where we stand in Civil Aviation to-day and where we may be heading during the next few years.

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   - 2.2. Subsidies and the Profit and Loss Account.
   - 2.3. The Requisites to Achieve the Purpose of Air Transport.
   - 2.4. Civil Aviation's Contribution to World Affairs.
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# PART I

## 2. THE PURPOSE OF AIR TRANSPORT

### 2.1. SOME FUNDAMENTALS.

The purpose which Air Transport should be designed to serve is, I suspect, all too often confused or ignored. I think that the essential contribution which Air Transport has to make to modern civilisation can be expressed, quite simply, in two words:—

Improved Communications.

Improved communications lead to traffic—both traffic robbed from older and less convenient forms of transport, and new traffic created by the new medium. Carriage of traffic is the fundamental task of all forms of transport. Air Transport, alone unimpeded by geographical barriers, has traffic-carrying potentials which are still largely unexplored, whether that traffic be passengers, freight or mails—businessmen to Brussels, honeymooners to Honolulu, or coals to Berlin. In the same way, estimates of traffic must form the basis of all operational planning and set the scale against which airline fleets and frequencies should be projected in terms of date as well as numbers.

Attraction of traffic is, therefore, the major task of every airline's commercial effort.

In order to attract the traffic on which its revenue depends, Air Transport must aim to offer superior carriage of passengers and goods between "A" and "B" than can any of the other means of transport which compete with it. The word "superior" in that sense will mean different things to different men—to some it will mean "swifter," to others "more frequent," "more comfortable" or "cheaper"—in a word, "more convenient."

In this connection the passenger service provided by an airline is an underlying factor which can influence its economic success. Passengers (unfortunately from an economic point of view) differ from a similar weight of meat, carried at freight rates, in their predilection for pampering. The job of the airline is to pamper them—within economic limits.

This selling of Air Transport to the passenger is a skilled and complex business in which the milk of human kindness (combined with, on occasion, harder spirits) has to be blended in exact, economic, proportions with creature comforts matched to the duration of a journey. Undoubtedly the way to sell Air Transport to the passenger is—in the words of a leading exponent—to offer "a kindly welcome, good service, pleasant personal attention, ending with *au revoir* but not good-bye." If successful, the new air traveller will be imbued with the urge to fly again; the seasoned veteran will receive those little attentions which he has come to expect. Both will be sent rejoicing away.

Passenger service need not be expensive to succeed—service with a smile costs nothing except a special effort in the bleak hours of the night—or on Monday mornings. But the success of passenger service has a lot to do with revenue in a hard, competitive World.

Carriage of freight or mail independently, in specialised cargo or postal aeroplanes, is another matter altogether—in some ways simpler. There seems little doubt that the scheduled cargo business will expand very much during the next few years and will call for different techniques from those required for passenger services.

Certainly, Air Transport, to be fully effective in its underlying purpose of improving communications, must be:—

SAFE
SWIFT
REGULAR
FREQUENT and
CHEAP.

It must, indeed, provide those "Three R's" of all means of transport:—

Reliability, Regularity and Revenue.

Just how safe, how swift, how regular, how frequent and how cheap Air Transport has to be, are the economic factors which will decide its success. I shall discuss each of these points later. But there can be no doubt that all these requisites are bound up in the one word Economics, which—I say again—is the foundation on which Air Transport operations must be set.

For instance—Safety. We hear a great deal of nonsense preached about safety—or lack of it—in the air. No one will deny that Air Transport must be made much safer yet. But the problem is one of economics not of sentiment.

Anybody can be almost 100 per cent. safe during the normal span of life—except for acts of God such as earthquake, lightning, tempest, pestilence, famine and flood—so long as he remains entirely static

and earthbound. Equally obviously an element—but only an element—of risk is introduced when he takes the air. The fact that a body is supported in the air some thousands of feet above the earth, endows it with potential energy for destruction—and the old gentleman who said, after his first flight, that he was not really scared because he had "not allowed himself to put his full weight down," had only psychological solace.

The fact is that the airline which has a poor safety record will lose its traffic. In the long run, the dangerous airline—so long as it is not supported uneconomically by its Government—must go out of business because people will not travel by it—if they do, some of them will not be there to repeat the adventure. On the other hand the airline which achieves 99.9 per cent. safety, but does so only by using such expensive ancillaries that its costs far exceed its revenue, will equally go out of business—or ought to do so, economically.

Safety, like water, should therefore find its own proper level. It must be a very high level, but it must be an economic level. At present it is neither high enough nor sufficiently economic.

The same arguments apply to Speed. If an airline operates a faster aeroplane than any of its competitors on a certain route it is certain to attract more traffic than its competitors, other things being equal. But, in the long run that will serve only so long as the fast aeroplane is capable of operating at a profit at the traffic loads it can attract—taking into account, if you like, the additional revenue derived in the form of a deficit grant from a subsidising Government who may set a national value on the speed attained. But even Government subsidies have their limits.

Similarly, the most economic aeroplane in the World will be of little value unless it attracts traffic. If it is so slow, or so uncomfortable, or so noisy that it gains insufficient traffic to meet its operating costs, it will not be worth operating. Apart from diplomatic or political services, which are another matter, economics are the ruling factor. And, subsidy or no subsidy, in the long run economics will decide.

We must face the fact that major civil airlines have never yet been operated at a profit, if all concealed and unconcealed subsidies are deducted—although certain short-haul services have made both ends meet. The reason for the uneconomic nature of long range operations, up to the present, has been that the profits from excess of revenue over direct operating costs have never been sufficient to meet the overheads. Two reasons have contributed to this: the fact that the aircraft themselves have not been able to carry sufficient payload to show an adequate margin of revenue over operating costs, and the fact that overheads have tended to be very high, because of the pioneering and developing nature of Air Transport and the relatively small scale of the business hitherto.

Subsidies have therefore been necessary.

## 2.2. SUBSIDIES AND THE PROFIT AND LOSS ACCOUNT.

Subsidies arise in many forms. There is the direct subsidy on operations, made in the form of deficiency grants to meet operating losses. There is the indirect subsidy in the form of mail payments, at rates which may be greater than the commercial scale. There is the hidden subsidy, which may be either in the payment of development costs on new aircraft or in the form of the provision, in greater or lesser degree, of airports and the ground aids necessary for airline operations.

All these forms of subsidy have as their purpose either one or other, or both, of two main objectives. They aim, firstly, at bridging the gap between total operating costs—including all ancillaries and all ground aids—and available revenue. This is a necessity until Civil Aviation establishes itself as a genuinely paying proposition. Secondly, and more narrowly, they aim at maintaining national Aviation in being in the face of foreign competition. In so far as this leads to international subsidy races it is a Bad Thing.

In order to understand the full implications of the subsidy position one must study the comprehensive Profit and Loss Accounts of Civil Aviation.

Precisely how much Civil Aviation is costing the World at present is difficult to estimate, although we do know that the total turnover of the airlines of the World has now reached about £1.5 million per day, and that they provide employment, in one way or another, for some 500,000 people.

Narrowing the field to British Civil Aviation, from such information as is generally available it appears that, in the immediate future, on the debit side British Civil Aviation will be costing somewhere about £71 million a year, all in. On the

## TABLE I.
## BRITISH CIVIL AVIATION
## A NATIONAL BALANCE SHEET
(Estimated figures)

| *Debit* | *Millions* | | *Credit* | *Millions* | |
|---|---|---|---|---|---|
| 1. Operating Costs ... ... | £30 | (42%) | 1. Operating Revenues ... | £23 | (32%) |
| 2. New Civil Aircraft Production ... ... ... | £17 | (24%) | 2. Aircraft Sales (Home) ... | £13 | (18%) |
| 3. Research & Development (Including new prototypes) ... ... ... | £ 9 | (13%) | 3. Aircraft Sales (Export) ... | £ 5 | (7%) |
| 4. Technical Ground Services (Air traffic control, lighting, navigational aids, etc.) ... ... ... | £ 8 | (11%) | 4. Charges for Technical Services ... ... | £ 2 | (3%) |
| 5. Airport Construction & Maintenance ... ... | £ 5 | (7%) | 5. Credit to be made nationally against:— (*a*) Provision for future revenues (*b*) National trade & communications (*c*) Political & diplomatic services (*d*) National prestige & security | £28 | (40%) |
| 6. Administration (Salaries and accommodation) ... | £ 2 | (3%) | | | |
| Total Annual Debit ... | £71 | (100%) | Total Annual Credit ... | £71 | (100%) |

| Deficits:— | |
|---|---|
| (*a*) Airport construction and maintenance programme plus technical services ... | £11 Million |
| (*b*) Operational Loss on Air Services ... | £ 7 Million |
| (*c*) Research and Development ... ... | £ 9 Million |
| (*d*) Administration ... ... ... ... | £ 2 Million |
| Total Deficits ... ... ... | £29 Million* |

*The difference between the sum of the deficits and the amount by which the revenues fall short of expenditure is accounted for by an estimated profit of £1 million on aircraft sales.

credit side, it will be gaining an income of some £23 million a year in direct revenues from traffic, a further £2 million a year in payments for ground facilities, and some £18 million from home and export sales of aircraft and equipment. The total income is thus around £43 million a year to set off against the £71 million expenditure. But some of the expenditure is in the form of investments for the future and some is a result of international obligations for the provision of designated airports. Other expenditures can be debited against the national advantages in the provision of rapid communication and increased trade and security, thus making possible the striking of a balance.

The Profit and Loss Account of British Civil Aviation can be set out approximately for a typical year in the immediate future as in Table I. I emphasise that the figures are in some instances "guesstimates." But they are, I think, of the right order.

These figures show that there is a gap estimated at some £28 million a year between the direct income from Civil Aviation in the United Kingdom and expenditure upon it. Those £28 millions (two pence halfpenny on the Income Tax) are the real subsidy price which we are having to pay for the building up of a national Civil Aviation which will mean as much to the nation in the future—both in its direct national attributes and in its international implications—as the Mercantile Marine has done in the past.

An interesting reflection is that, if the whole of the estimated £71 million annual cost of British Civil Aviation had to be paid out of revenues and sales without subsidy of any kind, the deficit could be eliminated by increasing passenger fares to about 1s. 6d. per

mile—which is some three times present charges. In other words the London-New York fare would have to go up from £87 to around £260 or the London-Sydney fare from £260 to £780.

Civil Aviation would then be self-supporting—provided that anyone travelled by air at all; which is doubtful.

As time goes on and Civil Aviation develops—as the traffic grows and the overheads are reduced—the Profit and Loss situation should appear much more favourable. Indeed, when the airports-building programme is more nearly completed, when revenues are increased both from carriage of traffic in more efficient aircraft and from the amenities provided at the airports, there are prospects that the direct expenditure will be balanced by the direct revenues at present fares. Then all the indirect benefits which Civil Aviation confers, in the form of increased trade and national assets, will be gained for nothing.

All this must be some way off. For the present we are much more conscious of the direct operating losses, quite apart from the additional heavy expenses at airports and in technical and administrative services.

For instance, in 1946-47 the three British Airways Corporations had an operating deficit of some £10.4 millions. The United States domestic airlines showed a loss of £5.2 millions, despite increases in fares. At the same time, United States international services lost approximately £100,000, a figure which may be substantially increased (possibly to £2 or £3 millions) when final adjustments to air mail payments have been made.

The comparatively small loss on United States international air services is an interesting commentary on the methods adopted for what has been called an indirect subsidy through mail payments. Out of a total operating revenue of £52 million, approximately £10 million, representing 19.2 per cent., was in the form of revenue from mails, although the mail ton miles were only 6.5 per cent. of the total payload.

This means that carriage of mails was at a much higher rate than carriage of other forms of traffic. The figures work out as follows for U.S. international air services in 1947:—

*Average Mail Receipts*—13s. 0d. per short ton mile.

*Average Passenger Receipts*—3s. 8d. per short ton mile (10.4 passengers per short ton).

*Average Freight Receipts*—2s. 7d. per short ton mile.

Mail was thus 3½ times more valuable to the U.S. airlines than was an equivalent weight of passengers and five times more valuable than an equivalent weight of freight. A way of looking at this is that the average cost per ton mile flown was 4s. 5d. and that passengers were subsidised by the mail to an extent sufficient to bring the rate down from its economic level of 4s. 5d. to 3s. 8d. per ton mile. The freight rate was brought down even further to a charge which the traffic would bear.

Even so, the U.S. Post Office has, up till recently, made both ends meet on its air mail contracts so that the revenue from mail was strictly on the basis of payment for services rendered and the taxpayer was not called upon directly. The system is therefore based on a rate of charge which can be borne commercially on mail—even though there has been a deficit during the past couple of years—a state of affairs which is, almost certainly, temporary. In this way, mail is used as a means of obtaining increased revenue to reduce passenger and freight rates to an amount the traffic will bear. In effect it is a form of purchase tax on letters. That is in contrast to a direct deficiency grant. All subsidies are bad. But of them all this seems to me the least bad because the high rate of mail payment is based on a charge that the mail traffic is willing to pay.

Even allowing for this indirect subsidy to U.S. international airlines through mails, the combined British and American operating loss on civil airlines in 1946-47 amounted to £15.7 million, representing a deficit of some 8.7 pence per aircraft mile flown, or a loss of £13,100 per aircraft for the year.

That is a poor state of affairs. But it is not necessarily fundamental to Air Transport. During this 12 months period the three British Airways Corporations were operating 222 aircraft of 19 different types, the Americans 971 aircraft of 6 different types—a total of 1,193 aircraft of 22 different types—far too many types for economic efficiency on the British side at least. During part of this time some of the best revenue-earning aircraft were grounded. It was a period of intensive building and training. And although load factors were good, payload percentages were

poor because many of the aircraft were converted military types and they were not properly matched to the stages they operated.

There is no doubt in my mind that, given the right tools, Air Transport is basically economic and that, before many years have passed, the losses can be entirely eliminated by revenue from a greatly increased turnover.

This is of course only on the airline side, in which — assuming efficiency — operating costs will be met by operating revenues with a useful balance to spare. What we have to do in addition is to make both ends meet on the ancillary services and building programmes.

A profit on operations will automatically mean a reduction in fares. A reduction in fares will create more traffic. More traffic will increase turnover and reduce unit overheads. The turnover should eventually be such that Civil Aviation will arrive at a completely self-supporting state. This must at present remain an article of faith rather than a sober fact. But the portents are there for those who heed them.

The only way to success is to start on a sound foundation. That means developing Civil Aviation on a firm economic basis, to achieve which there are a number of important requisites.

## 2.3. REQUISITES TO ACHIEVE THE PURPOSE OF AIR TRANSPORT.

I have already said that, in my view, the essential purpose of Air Transport is the improvement of communications—economically. To achieve this purpose there are four basic requirements: —

(*i*) EFFICIENT AIRCRAFT — economic to operate

(*ii*) EFFICIENT OPERATORS—devoid of crippling overheads

(*iii*) AN EFFICIENT GROUND ORGANISATION —meaning adequate airports and adequate air traffic control, and

(*iv*) AN AIR FARING OUTLOOK—on the part of the public which has to support Civil Aviation.

The most important requisite of these four is, probably, the last—the Air Faring Outlook —because on adequate public support depends our whole future in the air. The first three essentials—efficient aircraft, efficient operators and an efficient ground organisation—will all spring from the vital fount of public opinion. From it comes too the traffic potential on which all revenues must depend. Education of the public in air affairs should therefore have a high priority in any national planning. Every means of making the air available to the average man should receive all possible support.

My own view is that one of the best ways of doing this effectively is through the national encouragement of light aeroplane flying, gliding and aero-modelling. That is a subject to itself and not everyone will agree with me. But I am thinking here not so much of the air travellers as of encouraging the Air Faring Outlook to back up new expansion in the air. That must be allied, of course, with really reliable air services. However it is achieved, the Air Faring Outlook is of fundamental importance to any nation which wants to become great in this new medium of transport, business and security.

## 2.4. CIVIL AVIATION'S CONTRIBUTION TO WORLD AFFAIRS.

Given the foundations of efficient aircraft, efficient operators, an efficient ground organisation, and a supporting air faring outlook, Air Transport can contribute to national prosperity, security and well-being — and through them, to international solidarity—in three major respects: —

FIRST, through its direct earnings, on which any Air Transport Operating Industry must be founded. This may be termed the first and direct asset of Air Transport—*the revenue derived from air travel.*

SECOND, through its indirect influence on national and international trade. By means of the rapid communications provided by Air Transport a speeding up in the tempo of international business is made possible along the trunk air routes of the World. This may be termed the second, an indirect, asset of Air Transport — *increased trade through improved communications.*

THIRD, through the contribution of Air Transport to national security as a result of the manufacturing potential, the aircraft, the air crews and the airports which must be provided for Civil Aviation. This may be termed the third, and also indirect, asset of Air Transport—*the Security Factor.*

These three elements of Air Transport: —

*Air Travel* and its consequent revenue

*Improved Communications* and their influence on trade, and

*The Security Factor*

together form what might be termed the

elements of the Civil Air contribution to World affairs. They are, at once, the reasons for developing national Air Transport and what Air Transport has to offer, internationally, to the World at large.

To elaborate these three elements of Air Transport in a little more detail:—

*The First Element,* that which I have termed the direct asset from air travel, is related to the earning capacity of the individual aircraft. A modern aeroplane, intensively used, earns in revenue from payload between 100 and 200 per cent. of its capital cost every year. During its life a transport aeroplane will thus cover its prime cost many times over. From a national point of view this means that, whatever the operating costs, every transport aeroplane has a high earning power in foreign currency on international air routes—a form of invisible export. Reckoned in terms of an airline fleet this represents the creation of an Operating Industry which will have an annual turnover of many millions of pounds in both "hard" and "soft" currencies. The high revenue turnover results also in a high rate of employment per unit of capital cost. The fact is that in the reconversion year 1946-47 British scheduled airline operators took some £15 million in revenue and provided a wide field of employment — some say too wide. Estimates suggest that by 1960 on one route alone—the North Atlantic—the British Air Transport Operating Industry should be taking in revenue something like £30 million a year, of which the equivalent of £15 million may be in dollars. That is a most important invisible export and may well be termed, *the first Direct Asset of Air Transport—revenue from Air Travel.*

*The Second Element,* an indirect asset—the creation of trade through improved communications—is an intangible factor but is none the less important. Historically, trade has always followed the swiftest means of transport. To-day the old adage "Trade follows the Flag" is replaced by a new phrase "Trade follows the Air Route." Take, for example, the industrialist with business in Australia. Were he to go by sea the journey would take four weeks. Thus a return journey, combined with two weeks' work in Australia, would occupy not less than 70 days. By air the single journey takes four days. So an absence of only 22 days from London would be enough to take the business man to Australia and back and give him fourteen days there. The saving in time by air travel is a clear 48 days. The whole tempo of trade is speeded up. Fewer men can do more work in less time—which is one way of gauging business efficiency.

None of this takes into account the further intangible asset, which is the creation through Air Transport of travelling facilities not hitherto available, both for business and for pleasure. From the widest point of view of international relations, the more the peoples of the World can move around and see each other's way of life, the more quickly shall we arrive at an age of Peace and Plenty. After all, when Scotland and London were separated by 14 days of arduous journey by coach, Scots and Englishmen each regarded the other as savage and uncouth. Now that improved communications have allowed so many Scotsmen to come South that attitude may be said to be confined only to Parliament.

There is a further point. Civil airlines form a "shop window" for national products and national skill wherever they fly. They are themselves ambassadors of trade and goodwill, demonstrating operating techniques and passenger-handling ability as well as the equipment used.

For these reasons, in addition to the more obvious direct assets, efficient British air transport services are of the foremost importance to the United Kingdom and to the Commonwealth as a whole.

Not only are the services important in themselves because of the revenue they earn and the travel facilities they provide. They are important also to any manufacturing nation for the opportunities which they present for the demonstration, the development and the widespread use of nationally produced civil aircraft. Thus, employment of British aircraft on British air services is second only in importance to the services themselves for which the aircraft must be provided. We may be driven, temporarily, through the aftermath of war, to use on British air services some aircraft built by our friends overseas. Such a course is necessary to maintain and develop air services which are essential to the nation and the Commonwealth. But, in the long run, those services must depend on and flourish by use of British aircraft, just as the British Manufacturing Industry must depend on and flourish through the British air services.

All of us are confident that the British

Aircraft Industry can produce transport aircraft second to none. All of us know equally that such aircraft can be produced only as a result of operational experience—gained by intensive operation throughout the World. The one way to national aeronautical efficiency on the civil side is for British aircraft to sell on their merits in a World of fierce competition. By thus combining airlines and aircraft in a mutual evolutionary process the second element of Air Transport can be developed to the full in the indirect benefits which it can confer on trade and the national manufacturing potential.

To epitomise: The existence of the swift and improved communications provided by Air Transport is a vital factor in international trade. Those communications must be based on efficient aircraft. The nation which supplies the efficient aircraft, to make possible the swift communications, adds yet another trading asset to those provided by its operating Industry. Airlines and aircraft—operators and manufacturers — thus go together as the second element of Air Transport—*trade through communications.*

*The Third Element* of Transport Aviation is its contribution to national security. It has, I think, three points—the Aircraft Industry, the air crews and the airfields. Air Transport —indeed Civil Aviation as a whole—provides a means of keeping design teams busy and factories occupied. In time, demands for civil aircraft will undoubtedly build up, on civil requirements alone, an Industry of sizeable proportions. Already orders worth something like £13 million per year in direct production are springing from the still attenuated British civil airline operations. The research and development programme is also large. Civil Aviation can therefore be considered as an important factor in maintaining the aircraft manufacturing potential of any nation in time of peace. The competitive aspects of Air Transport certainly provide a spur to secure efficiency in design.

Civil aircraft and civil air crews are an important national asset in themselves. The civil airports along the trunk air routes of the World in time of emergency serve as the stepping stones of Air Power. For these reasons the third element of Air Transport is—*its contribution to national security.*

The clear meaning of what I have termed the "Three Elements of Civil Aviation" is that in each of its three main aspects Civil Aviation must take its place as one of the most important of the attributes of national prosperity, trade and security.

This implies that no nation which hopes to maintain itself in the forefront of World trade and World affairs can afford to neglect its Civil Aviation. But national Civil Aviation must be able to maintain its place on a sound commercial basis if it is to survive effectively in a hard commercial world and contribute to national welfare, instead of being a drain on the taxpayers' pocket. No business which is not founded on a true commercial basis can contribute throughout the years to national and international well-being.

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All that is by way of introduction to my main thesis. Having presented my belief that Civil Aviation is both worthwhile and capable of economic operations, and having attempted to analyse its economic and cultural components, I am now brought to the point of backing my belief with facts, deductions from those facts and reasoned conclusions.

I said earlier that, in my opinion, efficiency in aircraft underlies the whole subject because aircraft are the one stock in trade of the commercial operator. Returning to this I have approached the subject in two stages. The first is an analysis of what can be, and is being, achieved with existing aircraft equipment. The second stage consists of estimates of what might be gained from several lines of development now progressing. The difficulty —as always in Aviation—lies in establishing the facts from among as many variables as there are winds that blow.

## 3. GENERAL CONCLUSIONS

To bring forward here from the second part of this Paper the results of much study and discussion, the general conclusions I have reached, after analysis of all the relevant factors which I can determine, are as follow. There are 16 Points:—

POINT 1.

Air Transport is a Good Thing, both nationally and internationally and the more of it, on sound lines, the better.

POINT 2.

Air Transport is fundamentally a commercial business capable of being developed on sound economic lines but it has also important political, diplomatic, cultural, security and trading aspects.

POINT 3.

Because of its several, non-commercial, aspects some degree of subsidy is justified towards Air Transport in its formative stages. However, because subsidy is both internationally and commercially undesirable, leading as it does to national expenditure races and to concealment of operational inefficiency, direct subsidies should be regarded as an expedient to be eliminated as soon as possible.

POINT 4.

The least pernicious and the most stimulating form of subsidy is "payment for services rendered," such as for the carriage of mails, so long as the total sum paid to the airlines does not exceed the total sum paid by the public—in the mail instance, in buying air mail stamps for air carriage. A weighted air mail rate according to route requirements will, in this way, serve to encourage the development of services and frequencies required in the public interest without drawing directly on the taxpayer's pocket.

POINT 5.

Air Transport is essentially a business capable of becoming self-supporting when adequately developed with energy and enterprise. Provided that there are no international upheavals or economic slumps that stage should be reached during the next seven years. Ten to twelve years from now Air Transport should have achieved a sound commercial status without direct subsidy on any route.

POINT 6.

Progress has to be made in three main directions:—

Aircraft and engines—improving performance and reliability.

Air traffic control—eliminating congestion and delays.

Business efficiency—reducing costs and overheads.

POINT 7.

Overheads are at present running at an average of between 40 and 70 per cent. of total costs on the chief airlines of the World. The figures obtained are in association with direct costs which are themselves inflated in relation to revenue. In line with other transport business, Air Transport overheads should be reduced so that they amount to not more than 33 per cent. of the total operating costs, or to some 50 per cent. of direct operating costs, which themselves should be reduced. This can be done. A substantial increase in the business efficiency of the airlines is thus both necessary and possible.

POINT 8.

Air traffic control is costing some millions of pounds a year at present but is losing many more millions of pounds because air traffic has outgrown the control. Improved methods of air traffic control are essential. Indeed, turbine aircraft cannot be operated efficiently until that progress has been made. The most hopeful direction for progress appears to be that of automatic landing in all circumstances, the air crew and the ground scanners acting as monitors of the approach and landing. Until aircraft can be landed safely on individual runways in all weathers at a rate of not less than 30 per hour, the full realisation of Air Transport cannot be achieved.

Cheap, fast, air transport depends on the solution of the problems of air traffic control.

POINT 9.

Aircraft development must lie chiefly in the achievement of increased speeds at lower costs by means of reducing aerodynamic drag and by means of improved fuel consumptions. The results of progress in these directions will be more revenue miles for the same utilisation; more earnings for smaller expenditure. At the same time, delays and expenses covered by mechanical faults must be reduced far below their present high levels.

POINT 10.

Engine developments for civil aircraft are of the utmost importance. Each of the various types of power plant—from the long-established reciprocating engine to the rocket of the future—has its sphere of maximum use.

(*a*) *The standard piston engine* is suitable for operations over all but the very long ranges. In the present state of the art, its most economic performance is gained at heights of up to 25,000 ft., at speeds up to about 350 m.p.h. and, in present aircraft sizes, for stage lengths not exceeding 2,000 miles.

One of its great advantages is its flexibility of performance within its economic speeds and heights.

(*b*) *The compound piston engine* is most suitable for very long range operations at moderate speeds and at greater heights than the piston engine. In contemporary sizes of aircraft it has advantages over the piston engine for stage lengths of more than 2,000 miles. For long ranges the compound piston engine gives promise of being even more flexible than the standard piston engine, for heights up to about 35,000 ft. and speeds up to about 400 m.p.h.

(*c*) *The propeller-turbine engine* is, at present, most suitable for medium range operations at moderate speeds and heights—up to about 425 m.p.h. and 35,000 ft. When more fully developed for civil purposes, eventually, in conjunction with improved air traffic control, the propeller-turbine is likely to show advantages over the piston engine for all but very short or very long range operations and—in the largest sizes—for all operations. The chief difficulty with the propeller-turbine engine to-day is that, because of the small amount of interest in it for military purposes, almost all the development costs have to be spread over relatively few civil orders. The propeller-turbine is, in consequence, not receiving the amount of effort which it deserves and only a fraction of the development which is being concentrated on the turbo-jet. The establishment of a strong Air Transport Command in parallel with civil airlines will greatly assist the development of new power-plants.

(*d*) *The plain jet engine* is most suitable at present for moderate ranges at high subsonic speeds and at great heights—not less than 450 m.p.h. at not less than 30,000 ft. In the course of aeronautical development, the plain jet turbine will probably show improved commercial efficiency at supersonic speeds, up to about 1,500 m.p.h. at heights up to 75,000 ft. Although at high speeds the jet is more efficient than any propeller-driving engine, such speeds must always be costly to provide, although not necessarily less economic in operation because additional revenue may be attracted. In the immediate future the jet engine appears unlikely to be worth while for distances of less than 300 stage miles or greater than 2,000 stage miles. Its development beyond these confines will depend on the development of air traffic control to permit rapid landings.

(*e*) *The plain jet with after burning* is inefficient at subsonic speeds except as a take-off device. It is likely to prove suitable for cruising speeds of not less than 650 m.p.h. at 50,000 ft. and for supersonic cruising speeds of up to 2,000 m.p.h. at 80,000 ft. or more. The remarks on the plain jet apply with still greater force to the engine with "after burning" added.

(*f*) *The ram-jet* takes us, necessarily, into the almost unexplored realms of supersonic speeds, about which, one day, enough will be known to permit economic commercial operation. When the time arrives, the most satisfactory operating speed of a ram-jet aeroplane would appear to be around 2,200 m.p.h. at 50,000 ft. or more for stage lengths of around 1,000 miles.

(*g*) *The rocket power plant* applied to commercial aircraft is a further stage away. With it, speeds of up to 5,000 m.p.h. at not less than 100,000 ft. for stage lengths of some 500 miles appear possible. The economics at present look poor but may improve materially as nuclear science advances.

(*h*) *The rocket projectile* is at the moment the ultimate peak of high speed transport to which we can look forward. With theoretical intra-terrestrial speeds of up to 18,000 m.p.h. and inter-planetary speeds of 25,000 m.p.h., the rocket projectile may eventually bring any point of the earth's surface within an hour's block time of any other point—at an economic fare. Although such prospects may sound fantastic, the progression to a service "On the Hour to Anywhere in the Hour" is no greater than that from the stage coach of yesteryear to the 300 m.p.h. transport aeroplane of to-day.

(I should add that my more detailed economic and performance explorations in this paper go no further than the plain jet.)

POINT 11.

Types and sizes of aircraft equally have their own most suitable spheres of use.

(*a*) *The commercial helicopter*, in sizes of not less than ten seats, will find its most useful application in stages of from 50 to 200 miles, particularly for journeys involving short sea crossings. At present, helicopter costs are likely to be a good deal more than costs of fixed wing aircraft. But the helicopter is still at an early stage. Its development is likely to be rapid during the next ten years.

(*b*) *Short stage fixed wing aircraft* are, in general, incapable of competing with efficient surface transport for distances of less than 200 miles except where sea crossings, mountains, or other geographical barriers intervene. From 200 miles onwards the aeroplane shows increasing advantages over surface transport —with the turbine offering possibilities of marked reductions in costs when the "stacking" problems have been solved.

(*c*) *Medium and long stage fixed wing aircraft* represent the most advantageous developments in air transport vehicles. Large aircraft are necessary for long stage routes. But once the largest economic payload has been decided and allied to the longest route which requires to be operated, then every technical development will tend to reduce the size of aeroplane required for the job. At the present time aircraft of between 100,000 and 300,000 lb. represent the peak of development for long stages. We shall probably see bigger types still before evolution begins to reduce the size.

POINT 12.

One of the most important factors contributing towards economic operations is the matching of aircraft size and types of aircraft to the routes and stage lengths over which they will be required to operate. In the present state of the art a 100,000 lb. aeroplane is most suitable for stages of about 1,750 miles, whereas a 300,000 lb. aeroplane is most suitable for stages of about 3,000 miles. For the same most-economic stage distances and the same payload, turbine aircraft will have to be larger than aircraft powered with conventional engines until turbine consumptions have been improved very much compared with present prospects.

POINT 13.

Total annual operating costs vary in relation to three factors:—

(i) The fixed annual costs.
(ii) The hourly cruising costs.
(iii) The costs associated with take-off and landing.

They are influenced by the overheads, the number of hours flown in a year and by the stage length operated.

POINT 14.

Direct operating costs are related to hours flown. Revenue is related to miles covered. Therefore speed, so long as it is gained by development, is potentially economic even for short distances, not so much on account of the shortened journey time—which may not be significant—but because of the increased revenue earning capacity made possible for a given utilisation.

POINT 15.

Ground costs are of major importance in the wider issues of Air Transport. Developments in airport runways, both in length and strength, have about reached an economic ceiling. New aircraft must be designed to fit existing airports. By taking advantage of methods of assisted take-off and by concentrating on multi-wheel undercarriages—later perhaps eliminating the undercarriage altogether—the difficulties can be met.

POINT 16.

The long term trend of Air Transport is towards higher speeds at lower costs. Efficient operations, with advanced types of aircraft matched to the routes, hold out promise of economic costs no higher per mile than those of surface transport.

# PART II

## 4. OPERATING ANALYSES (PRESENT TRENDS)

### 4.1. THE STATUS IN 1948.

Foundations for any general survey must be laid on established fact. In Aviation all facts are difficult to establish with exactitude because of the almost infinite number of variables concerned. In addition, post-war Civil Aviation, in 1948, has not completely emerged from the transition period from war to peace. Converted military aircraft are still in widespread use on the airlines of the World, while ground facilities suitable for commercial Aviation are still under construction everywhere. Many new technical developments are also in course of introduction.

Hence, at present, Air Transport is nowhere near stability. Such annual accounts and statistics as are now available are for the years 1946 and 1947, during which reconversion was at its peak.

Even so, some valuable indication of trends of progress can be discovered from an

examination of existing figures. I do not intend to go into detail here on the growth of air traffic—although it is worth noting in passing that the traffic carried on British airlines in 1947-48 was 40 per cent. greater than that of the previous year; growing to 41.6 million aircraft miles and 627,000 passengers carried for 470 million passenger miles. United States airlines flew 403 million aircraft miles and carried 14 million passengers in 1947. According to a study made by the Civil Aeronautics Board, between 1938 and 1946:—

whereas the United States national income, corrected for price changes, increased by 80 per cent.

the passenger miles flown on domestic air services increased by 990 per cent., and

the passenger miles flown on international air services increased by 1,780 per cent.

Which is a healthy sign.

4.1.1. SAFETY.

Nevertheless the progress of commercial Aviation has been retarded by one factor above all else. Undoubtedly the aspect of present-day Air Transport which worries the "man-in-the-street" most and prevents him flying more is the so-called safety standard.

We all agree that Air Transport is not yet safe enough. But the fact is that Air Transport is nothing like so unsafe as is suggested by the headlines we see in the non-technical Press. There are at this precise moment something like 15,000 fare-paying passengers actually in the air in some 1,000 aircraft on the regular airlines of the World. Yet, in comparison with this sizeable airborne population which is maintained day and night and is constantly growing, even the newspaper reports of accidents are fairly infrequent.

Indeed, in the United States last year, statistics show that there were more people kicked to death by donkeys than were killed in Air Transport. One must assume that a very dangerous breed of donkey is reared in the United States. But as 12.6 million people flew for 6,055 million passenger miles on the U.S. domestic airlines in 1947 and (although it was a bad year for accidents) only 199 of them were killed, and as I very much doubt whether the donkey miles approached this figure, it may be assumed that it is more dangerous to approach a donkey in the United States than to fly in a transport aeroplane.

Further evidence comes from the United States, of a more sober kind. Mr. Jerome P. Lederer, prominent in U.S. Aviation Insurance, speaking before the Institute of the Aeronautical Sciences in New York in January 1948, pointed out that a passenger would have had to travel 560 million miles on U.S. airlines in 1946 (a good year) before he would be killed. That is, 1.8 deaths per 1,000 million passenger miles—or the equivalent of 4,170 journeys to the moon and back again per passenger death. I trust that the Interplanetary Society will achieve similar results.

On a comparative basis, the statistics for the two-year period 1944 to 1946 were:—

Omnibuses: 1.9 *deaths* per 1,000 million passenger miles.

Passenger trains: 2.1 *deaths* per 1,000 million passenger miles.

Scheduled airlines: 17.0 *deaths* per 1,000 million passenger miles.

Motor cars and taxis: 27.0 *deaths* per 1,000 million passenger miles.

Thus, although air travel in those two years was eight times less safe than riding in a train, it was nevertheless much safer than in a private car or taxi. Lederer remarked:

"Therefore it is safe to conclude that the magnitude of safety achieved by the airlines would be fully acceptable to the public if the public did not receive a distorted picture of airline safety from the Press."

The over-prominent news value of Aviation is, I am afraid, one of the handicaps under which it has to labour. That should act as an additional spur to efforts directed at improving safety.

Of all the fatal accidents to scheduled transport aircraft—in 1947 (a bad year) one per 50 million aircraft miles—40 per cent. occur during approach and landing in bad weather, while, in other forms of civil flying, 70 per cent. of the accidents are caused by either stalls, spins or low flying.

A concentrated attack on the problem of bad weather landings and on producing non-spinnable private aircraft, combined with a campaign against low flying, would have most valuable results in improving the safety record. My own view is that we shall have to come to a system of automatic landings for all transport aircraft; thus combining the advantages of safety with improved regularity, once a satisfactory system can be evolved. The same standard of safety on

regular airlines as that achieved by the railways is certainly within reach—economically.

4.1.2. THE STATISTICAL BACKGROUND.

When we turn to the statistics available for current airline operations, several encouraging trends can be disentangled. Table II indicates some of the facts and figures as they pertain to six of the World's leading airlines engaged in international operations during recent 12 months periods.

Not wishing to get involved here in a discussion of the relative efficiencies of competing airlines, on the basis of figures which probe a little more deeply beyond those of the normal accounts, I have labelled the six different companies as Airline "A," Airline "B," etc. Invidious comparisons may, therefore, be avoided.

The statistics are set out in Table II* for the six airlines in order of number of annual miles flown per aircraft—the best economic results being gained by the airline operating the most annual aircraft miles, the worst figures from that flying the least annual miles per aircraft.

Examination of the figures shows that, even in these difficult times, there are airlines which can show a surplus of revenue over operating costs, although, admittedly, a proportion of the revenues are in the form of mail subsidies.

The best margin of profit is nine per cent. of the turnover, whereas one airline showed a loss of 40 per cent. on its turnover. The average figure comes out at a loss of about sixpence per aircraft mile flown or a loss of twopence per ton mile of payload carried.

Further inspection emphasises the well-known fact; that a profit can be gained only by associating a reasonably high revenue load factor with low overheads and high aircraft utilisation—in other words, the aircraft must be kept flying day and night and must be attractive enough commercially to achieve economic load factors. At the same time, direct costs must be kept low by good detail and general design of aircraft and by efficient maintenance and operation, while overheads are reduced to a minimum by use of as few types of aircraft as possible and by streamlined administration.

Those overheads are very important. At present they are running at rather more than half the total operating costs—Table II shows the average for these six airlines to be 54.5 per cent. But they can be reduced, and one airline—Airline "D"—well known for its efficiency of management, pruned its overheads to 33 per cent. of the total costs (half the direct operating costs) during the 12 months period reviewed. That target figure of 33 per cent. for overheads must be achieved much more widely if profits are to be made from Air Transport. The airline out of the six which suffered the most serious losses in the year had overheads standing at 53.5 per cent. of the total costs, while its revenue was low. The reasons behind these figures for Airline "F" were partly an uneconomic multiplicity of types of aircraft operated at a low utilisation and partly operation of aircraft of poor commercial efficiency: the tale is reflected in the figures —a £54 loss for every hour flown.

Some people, not in the business, may be surprised to see that the total operating costs average more than £140 per aircraft hour flown—of which about £65 per hour is direct costs and the other £78 per hour, overheads. These figures work out at an average of just under 15 shillings per aircraft mile, of which 6s. 7d. is direct flying costs.

The average payload carried was 2.9 tons; representing 10 per cent. of the gross weight of the aircraft. Block speeds varied between 172 m.p.h. and 225 m.p.h.

Just as the "average man" has few precise counterparts in real life, so the "average airline" is difficult to find. Nevertheless, the "average man" and the "average airline" are useful as illustrations of trends of development. From the figures compiled for the six international airlines in Table II, one can see that the present trend is for a 29 ton (65,000 lb.) aeroplane to be required to carry an average payload of 2.9 tons (6,500 lb.) for a stage length of 903 miles at a block-to-block speed of 195 m.p.h., with a frequency of 3.65 round trips per week, making a total of 1,104 tons carried in the year. The cost of carrying this payload for an average duration of 4.63 hours works out at £662, or 5s. 5d. per ton mile; the equivalent of about 5.89 pence per passenger mile. Revenue works out at 4s. 11d. per ton mile, so that an increase of seven per cent. in revenue load factor, or of 20 m.p.h. in speed—provided it could be gained without extra cost—would eliminate the deficit.

These approximations from past experience are useful as indications of the trends of costs

* Large tables which do not appear with the text will be found at the end of the Paper.

and performance. They can be analysed further and used as a check on estimates for the future.

The statistics make quite clear the fact that operating analyses must be based on two distinct sets of figures. They are:—

*First.* Performance characteristics in operating conditions over required stage lengths for the type of aircraft concerned.

*Second.* Operating costs and revenues for the same aircraft operated under the same conditions and over the same stages.

A study on these lines for types of contemporary aircraft is contained in this second part of my Paper.

## 4.2. CONTEMPORARY TYPES OF AIRCRAFT.

### 4.2.1. SELECTED TYPES FOR ANALYSIS.

In an attempt to establish the parameters of performance and of cost which embrace types of commercial aircraft as we know them to-day I have analysed, in some detail, the operations of seven types of contemporary aircraft, most of which are well known and established. They cover all sizes, from the smallest and simplest commercial feeder-line type up to the biggest trans-Atlantic air liner. Hence the analyses of operations cover not only the range of aircraft but the range of operating conditions as well.* I have not included any flying boats among the seven because marine aircraft form a separate economic subject of their own.

The seven landplanes I have selected as typifying present or imminent types are as shown in Table III.

Most of these types are well known and four of them have a comprehensive background of operating experience.

An ironical fact is that the establishment of factual data for aeroplanes which have been in service for some years, and have been developed considerably thereby, is a good deal more difficult than for a new type which has either just completed its performance trials or still has a performance only on paper.

One of the seven types in the list does require a little explanation. It is the aeroplane I have described as the "Commonwealth and Empire Orion I" with four 5,000 h.p. "Orion Major" engines. I must stress that this "Orion" is an entirely hypothetical aeroplane included so as to fill the gap in operating performance between the 105,000 lb. Constellation and the 300,000 lb. Brabazon I. The "Orion Major" engines are, however, founded on fact. Some years ago the Bristol Aeroplane Company planned a 105-litre 28 cylinder engine of this name. It was to have been a four-row development of their "Orion," which itself was intended as the next step in size after the Centaurus. Unfortunately national engine policy in the stress of war did not permit its development. Were such an engine available in a developed form to-day we should no doubt welcome it enthusiastically. I have assumed its existence for the purposes of this study and I have married it to the hypothetical airframe of the 90-ton "Orion I" 92-passenger long-range aeroplane.

For the rest, the Rapide of 1936 has set an economic standard which cannot be surpassed by any 1948 aeroplane of equivalent size, although the Rapide could not hope to meet future I.C.A.O. standards on single-

* (Here it is my pleasant duty to acknowledge the help, assistance and encouragement which I have received from so many hands. In particular I want to thank my two colleagues, Mr. J. G. Simms, O.B.E., M.A., and Mr. P. W. Brooks, B.Sc., A.C.G.I., A.F.R.Ae.S., who have both been untiring in compiling data, in constructive criticism, and in discussion of problems thrown up during preparation of the Paper. They have both contributed materially to it. In addition I gratefully acknowledge the help, advice and data so freely accorded to me by Airspeed Ltd., Sir W. G. Armstrong Whitworth Aircraft Ltd., the Bristol Aeroplane Company Ltd., British European Airways, the British Overseas Airways Corporation, the de Havilland Aircraft Company Ltd., Mr. C. Jackson, B.Sc., A.C.G.I., A.F.R.Ae.S., Mr. C. Dykes, M.A., Captain A. G. Lamplugh, C.B.E., F.R.Ae.S., Captain H. Spry Leverton, O.B.E., the Lockheed Aircraft Corporation, the Ministry of Civil Aviation, the Ministry of Supply, Olley Air Services Ltd., Rolls-Royce Ltd., Vickers-Armstrongs Ltd., Mr. A. H. Watson, M.A., F.S.S., and Captain J. Laurence Pritchard, Hon.F.R.Ae.S., Mrs. Joan Bradbrooke, A.R.Ae.S., and other members of the Staff of the Royal Aeronautical Society. In the preparation and checking of the manuscript, tables and figures I am grateful for the assistance of the Misses J. E. Bagshaw, P. E. Copland, V. Hart, J. Gwilliam and D. Stansfield and of Messrs. R. E. G. Davies and R. V. Easy. Although I take full responsibility for the opinions expressed in this Paper, none of which necessarily reflects any official views, without these and many other persons and bodies, the Paper could not have been written.)

## TABLE III

### SELECTED CONTEMPORARY TYPES OF COMMERCIAL AIRCRAFT

(Covering a range from 5,750 lb. gross weight to 300,000 lb. gross weight)

| | | |
|---|---|---|
| 1 | de Havilland D.H.89a RAPIDE III (Two 205 b.h.p. D.H. Gipsy Queen III) | 5,750 lb. |
| 2 | de Havilland D.H. 104 DOVE I (Two 320 b.h.p. D.H. Gipsy Queen 70) | 8,500 lb. |
| 3 | Douglas D.C.-3c DAKOTA III (Two 1,200 b.h.p. Pratt & Whitney Twin Wasp R-1830-92) | 28,000 lb. |
| 4 | Airspeed 57 AMBASSADOR (Two 2,700 b.h.p. Bristol Centaurus 66) | 52,000 lb. |
| 5 | Lockheed 749-79-34 CONSTELLATION IV (Four 2,500 b.h.p. Wright Cyclone 18 R-3350-BD1) | 105,000 lb. |
| 6 | "Commonwealth & Empire" ORION I (Four 5,000 b.h.p. Orion Major) | 200,000 lb. |
| 7 | Bristol 167 BRABAZON IB (Eight 3,500 e.h.p. Bristol Proteus) | 300,000 lb. |

engine performance. The Dove, equipped with most modern conveniences, is a size larger than the Rapide and may be considered as representing one trend of development from it. Doves are now in service in numbers throughout the World and are proving deservedly popular.

The civil Dakota, the conversion from the military version of the DC-3, is in use throughout the World in larger numbers than any other type of commercial aeroplane. This aeroplane—alias "Dakota," C-47, "Skytrain," DC-3—has set a standard by which all other civil aircraft of similar size have come to be judged on performance and on economics, for better or for worse—although it, too, could not comply with I.C.A.O. standards.

Jumping to double the weight, the Airspeed Ambassador may be taken as representing the most advanced piston-engined commercial aeroplane of its size yet in prospect. The Ambassador is on order for British European Airways and, like the Rapide, the Dove and the Dakota, each in its class, is likely to become a classic type, with us for many years to come.

Doubling the size again, the Lockheed Constellation is recognised everywhere as another classic aeroplane. Some 135 Constellations are now in service on long-distance airlines all over the World. It has a longer range than any contemporary aeroplane and represents about the peak of performance with present types of power plant in aircraft of that weight.

Doubling the size again, we come to the hypothetical Orion of 200,000 lb. which I have already mentioned. A further jump of 100,000 lb. brings us to the Bristol Brabazon I, which is the largest commercial landplane yet on the stocks. The first prototype of the Brabazon I will have eight Centaurus engines coupled in pairs, delivering 20,000 h.p. through four sets of counter-rotating propellers. The production version, represented by the second prototype, will have eight Bristol Proteus propeller-turbines and a total of 28,000 e.h.p. for take-off. This Proteus-Brabazon IB is the version I have taken for the purpose of analysis.

4.2.2. PRIME COSTS.

In these days about the first thing at which an operator looks in a new aeroplane is its prime cost. The price may not be so important to the economics as is the performance, but, affecting as it does the amortisation, the insurance, the interest on capital and the cost of spares and replacements, it has none the less a major influence on the accounts.

The prices of aircraft, like other commodities, have been soaring upwards since the War. In addition, the amount of

navigational paraphernalia which has to be carried around in a modern transport aeroplane adds materially to its weight and to its cost. The figures I have quoted in Table IV for the prime costs of the seven selected types of contemporary aircraft are somewhat above the normal list prices of those aircraft. This fact is, in the main, accounted for by the amount of equipment which I have assumed is installed to bring them up to meticulous operating standards—including de-icing, a full range of instruments, complete radio, furnishings and, where appropriate, galleys, pressurisation, refrigeration and the like.

Table IV shows that, apart from the elderly Rapide and Dakota, the prime cost of the various aircraft considered varies between £2.35 and £4.34 per lb. of designed gross weight—the lower figure being for the smallest type, the higher figure that of the largest machine. Examination of the selling price of a large number of other British and American transport aircraft of contemporary types indicates that the prices of almost all of them come within these two limits.

The two older types, the Rapide and the Dakota, have prices to-day which are rather less than half the cost per lb. of their modern rivals. Both these 1936 types are no longer in production and the prices quoted are either their secondhand market value or the cost of the aircraft converted from their military equivalents, the Dominie and the C-47. These prices, which work out at £0.96 per lb. for the Rapide and £0.81 per lb. for the Dakota are, in fact, approximately the same as their original selling prices in 1936 when all costs were about half those which prevail to-day. The two elderly types may therefore be considered apart, when looking at present-day production costs. Their low cost is one of the chief reasons why they can remain in active competition with newer aircraft incorporating the benefit of years of further progress in design.

At first sight, it might be thought that a curve could be plotted for cost per lb. against all-up weight and that such a curve would indicate the increase of price per lb. to be expected with increase in size. On further examination such a prospect is seen to be based on over-simplified assumptions. The influence of many variables, in particular the number of aircraft produced and the method of covering and apportioning the development costs, is seen to have a far greater influence on the specific costs per lb.

TABLE IV.

ANALYSIS OF ASSUMED PRIME COSTS

SELECTED CONTEMPORARY AIRCRAFT

| | AIRCRAFT | Gross Weight | Prime Cost complete with all equipment | Production Number | Prime Cost per lb. of gross weight. | Prime Cost of Engines | Engine Cost per take-off horse-power | Prime Cost of Pr jellers. | Propeller Cost per take-off horse-power | Prime Cost of Radio | Prime Cost of equipped airframe less radio | Weight of equipped airframe | Cost per lb of equipped airframe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | de Havilland RAPIDE III | 5,750 lb | £5500 | 700 | £0·957 | £1500 | £3 7 | £200 | £0 492 per b.h.p. | £450 | £3,350 | 2190 lb | £1·53 |
| 2 | de Havilland DOVE I | 8,500 lb. | £20,000 | 300 | £2 352 | £3900 | £5 65 | £1230 | £1 850 per b.h.p | £2,000 | £12870 | 2990 lb | £4 3 |
| 3 | Douglas DAKOTA III | 28,000 lb. | £22,700 | 10926 | £0 811 | £2400 | £1 0 | £1000 | £0 417 per b.h.p | £1400 | £17900 | 11,480 lb. | £1 56 |
| 4 | Airspeed AMBASSADOR | 52,000 lb. | £150,000 | 35 | £2 885 | £30,000 | £5 55 | £5,000 | £0 927 per b.h.p. | £5,000 | £110,000 | 22690 lb. | £4 85 |
| 5 | Lockheed CONSTELLATION IV | 105,000 lb. | £275,000 | 140 | £2 620 | £45,000 | £450 | £6,000 | £0 6 per b.h.p. | £7,000 | £217,000 | 39827 lb | £5 45 |
| 6 | Commonwealth & Empire ORION I | 200,000 lb. | £608,000 | | £3 04 | £110,000 | £5 50 | £20,000 | £1 0per b.h.p. | £7,000 | £481,000 | 72,500 lb. | £6 64 |
| 7 | Bristol BRABAZON 1B | 300,000 lb. | £1,300,000 | 6* | £4 334 | £212,000 | £7 65 | £32,000 | £1 142 per b.h.p. | £10,000 | £1,046,000 | 108,500 lb. | £9 64 |

* Estimate of number required for full North Atlantic operations.

than does increase in size. Indeed, except for the very small and simple aeroplane, size appears to have little effect on specific cost except to limit the number produced.

Design and development costs to-day are so great that no private company can contemplate developing a major transport aeroplane solely as a private venture. This fact is going to have a profound influence on the progress and direction of aeronautical design. It means, in effect, that Government support is essential in one or another way before a large new civil aeroplane can be produced.

I have set out, in Table V, some typical design and development costs for modern British and American transport aeroplanes produced *ab initio*, ranging from the four-ton Dove up to the 140-ton SR-45.

From this Table one can see that these costs vary between £20 and £40 per lb. of gross weight, influenced by many factors. A reasonable average appears to be some £30 per lb. of designed gross weight—on the whole rather more for the American types on which design work tends to be on a more lavish scale.

This average of around £30 per lb. includes costs of design, mock-up, construction of two prototypes, purchase of engines and ancillaries, development work, test flying and completion of manufacturer's development flying up to Certificate of Airworthiness standard, together with appropriate overhead charges—but with operational proving flights still to be undertaken. The figure represents, in fact, the cost of bringing a new aeroplane up to the stage of its operational proving trials and production planning. It does not include anything for design or construction of production jigs and tools, but some of the engine development charges for a new type may be included in the purchase price of the engines. The variation in the apportionment of these engine costs accounts for a good deal of the variation in cost per lb. in the Table.

Examination of Table V shows that these design and development costs remain reasonably stable per lb. of designed gross weight throughout the range of sizes. Obviously, a small and simple two-seat Club trainer would be cheaper to build per lb. than would a highly complex, pressurised, transport. On the other hand, the trend of large aircraft is to be cheaper per lb. for a given quantity—this tendency cancelling the other. The proportion of engine powers and costs in relation to the total will also vary and influence the development costs. For new, turbine-powered, types, the engine costs are likely to be rather high, increasing the development costs.

But, by and large, the figure of £30 per lb. of designed gross weight appears to be a fair average.

An interesting fact is that both the really big aircraft, the Brabazon I and the SR-45, have estimated development costs which are relatively cheap per lb. of gross weight. One reason for this is that neither of them is carrying the full engine development charges on the Proteus. Were these amounts to be added, their costs would go up to about the average £30 per lb. In addition, the SR-45 is being built without prototypes, in the accepted sense of that word. New aircraft of more than 100 tons gross weight are still something of a manufacturing adventure, and the estimated figures may perhaps turn out to be somewhat low.

Taken all round, any new transport aeroplane which completes all its trials at a cost of less than £30 per lb. in present-day conditions, will have achieved something quite outstanding.

These facts and figures, naturally, react on the selling price of the aeroplane, depending on whether any proportion of the development costs can be written off against national research, and how much has to be recovered over the production order—whatever size that may be.

For instance, the cost of 50 production aeroplanes of 100,000 lb. gross weight may work out at about £300,000 each if all design and development costs have to be recovered over that number. But, were all the design and development costs, plus jigging and tooling, to be offset against say, a military transport order, the price to an airline could be reduced by some 26 per cent., to about £220,000 per aeroplane. That is an important difference when it comes to operating costs. Over smaller numbers the difference would be still greater.

Detailed analysis of available data for costs of the development and production of transport aircraft on both sides of the Atlantic, some of which is shown in Table V, brings out a number of interesting figures. Reduced to broad approximations they may be stated thus:—



* Estimate of number required for full North Atlantic operations.

1. Cost of design, mock-up, construction of two prototypes, purchase of engines, test flying, and manufacturer's development flying up to C. of A. standards, plus appropriate overheads.

   £30 *per lb. of designed gross weight* (*or* £15 *per lb. of prototype weight*).

2. Cost of design and construction of jigs and tools for quantity line production, plus jig and tool room and manufacturing overheads, and other pre-production costs (including unbalanced high component and fitting costs on small production).

   £10 *per lb. of designed gross weight*. (This figure will vary fairly widely according to rate of output desired. High tooling costs will tend to reduce production labour costs.)

3. Cost of materials, labour and overheads for construction of quantity production aircraft.

   £2.2 *per lb. of designed gross weight*.

## REPRESENTATIVE DESIGN, DEVELOPMENT AND TOOLING COSTS FOR MODERN TRANSPORT AIRCRAFT

TABLE V

(Produced *ab initio*)

| Type of Aircraft | Number of Prototypes | Production gross weight | Approximate Cost of Prototype Design and Construction, Engines, Development Flying and Overheads | Design, Prototype and Development Cost per lb. gross weight | Costs of Jigging and Tooling | Number of Production Aircraft | Approximate Fully equipped Selling Price per Production Aircraft | Selling Price per lb. of Production gross weight |
|---|---|---|---|---|---|---|---|---|
| 1. de Havilland Dove ... | 2 | 8,500 lb. | £342,200 | £40·3 | £560,000 | 300 | £20,000 | £2·35 |
| 2. Armstrong Whitworth Apollo ... | 2 | 37,000 lb. | £1,100,000 | £29·7 | — | — | — | — |
| 3. Vickers-Armstrongs Viscount ... | 2 | 39,000 lb. | £1,170,000 | £30·0 | — | — | — | — |
| 4. Consolidated Vultee Convairliner | 2 | 40,500 lb. | £1,375,000 | £34·0 | £1,630,000 | 300 | £117,500 | £2·9 |
| 5. Airspeed Ambassador | 2 | 52,000 lb. | £1,425,000 | £28·0 | — | 100 | £150,000 | £2·88 |
| 6. Lockheed Constellation | 2 | 105,000 lb. | £3,360,000 | £32·0 | £2,623,500 | 180 | £275,000 | £2·75 |
| 7. Lockheed Constitution | 2 | 196,000 lb. | £6,750,000 | £34·4 | — | — | — | — |
| 8. Bristol Brabazon ... | 2 | 300,000 lb. | £7,000,000 | £23·4 | — | 4 | £1,300,000 | £4·35 |
| 9. Saunders-Roe SR-45 ... | 3 | 315,000 lb. | £6,500,000 | £20·6 | — | 4 | £1,100,000 | £3·5 |

## TYPICAL DEVELOPMENT AND PRODUCTION COSTS

TABLE VI

| | Average Cost per lb. | 28,000 lb. aeroplane | 50,000 lb. aeroplane | 100,000 lb. aeroplane | 200,000 lb. aeroplane |
|---|---|---|---|---|---|
| 1. Design and development costs, including two prototypes | £30 | £840,000 | £1,500,000 | £3,000,000 | £6,000,000 |
| 2 Jigging and tooling costs | £10 | £280,000 | £500,000 | £1,000,000 | £2,000,000 |
| 3. Total cost of two prototypes, plus 10 production aircraft with all operating equipment | £6·2 | £1,735,000 (£173,500 per aircraft) | £3,100,000 (£310,000 per aircraft) | £6,200,000 (£620,000 per aircraft) | £12,400,000 (£1,200,000 per aircraft) |
| 4. Total cost of two prototypes, plus 25 production aircraft | £3·8 | £2,660,000 (£106,250 per aircraft) | £4,750,000 (£190,000 per aircraft) | £9,500,000 (£380,000 per aircraft) | £19,000,000 (£760,000 per aircraft) |
| 5. Total cost of two prototypes, plus 50 production aircraft | £3 | £4,200,000 (£84,000 per aircraft) | £7,500,000 (£150,000 per aircraft) | £15,000,000 (£300,000 per aircraft) | £30,000,000 (£600,000 per aircraft) |
| 6. Total cost of two prototypes, plus 100 production aircraft | £2·6 | £7,280,000 (£72,800 per aircraft) | £13,000,000 (£130,000 per aircraft) | £26,000,000 (£260,000 per aircraft) | £52,000,000 (£520,000 per aircraft) |
| 7. Total cost of two prototypes, plus 150 production aircraft | £2·46 | £10,350,000 (£69,000 per aircraft) | £18,500,000 (£123,250 per aircraft) | £37,000,000 (£246,500 per aircraft) | £74,000,000 (£493,000 per aircraft) |
| 8. Total cost of two prototypes, plus 200 production aircraft | £2·4 | £13,420,000 (£67,200 per aircraft) | £24,000,000 (£120,000 per aircraft) | £48,000,000 (£240,000 per aircraft) | £96,000,000 (£480,000 per aircraft) |
| 9. Total cost of two prototypes, plus 300 production aircraft | £2·33 | £19,600,000 (£65,400 per aircraft) | £35,000,000 (£116,500 per aircraft) | £70,000,000 (£233,000 per aircraft) | £140,000,000 (£466,000 per aircraft) |

The fact that these average figures do not include a full apportionment of the costs of bench running and flight development of engines must be emphasised again. These items are very expensive indeed. But, because they can be recovered over a very large number of engines in both military and civil use, they are not normally assessed at their full amounts in calculating costs of individual transport aircraft.

With these provisos, the costs for the various stages of the development and production of four typical transport aircraft can be set out as shown in Table VI. The total costs quoted are the fully-equipped costs, including all instruments, furnishings and fittings, radio and galley—in fact, the aeroplane ready to carry its first passenger. These figures assume also the inclusion of a small margin of profit to the manufacturer.

The total costs arrived at in this generalisation cannot be expected to be precisely accurate. But they do show the order of costs for varying production batches of aircraft of different sizes. They show, for instance, that a batch of 50 production aircraft of 100,000 lb. gross weight would be cheaper per aircraft than a batch of only 10 production aircraft of 50,000 lb. gross weight.

The facts are expressed, perhaps more clearly, by the curve shown in Fig. 1 in which cost per lb. of gross weight is plotted against the number produced. The point which stands out is that a production batch of less than about 50 aircraft results in a much higher unit cost than would be obtained over a large number. Cost per unit falls at a much slower rate for batches of more than 50 aircraft. But, if the cost is to be reduced to say £2.5 per lb. of gross weight, rather more than 100 aircraft must be built.

All this explains why very large aircraft tend to be expensive per lb. of gross weight. For only ten production aircraft total costs run in the region of £6.0 per lb.—although the low-production end of the curve is somewhat academic in that no aeroplane would be

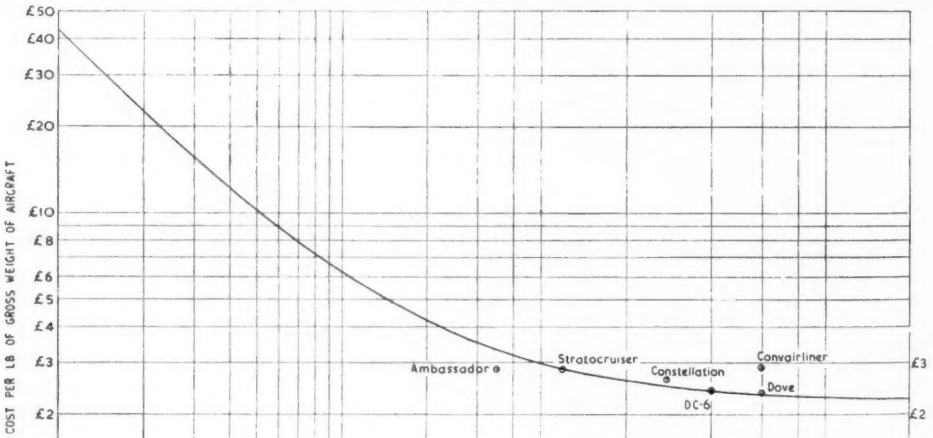


Fig. 1.
Typical production costs of modern aircraft.

| | | | |
|---|---|---|---|
| 1 off | ... ... ... | £42.2 per lb. | |
| 10 off | ... ... ... | £ 6.2 per lb. | |
| 20 off | ... ... ... | £ 4.2 per lb. | |
| 50 off | ... ... ... | £ 3.0 per lb. | |
| 100 off | ... ... ... | £ 2.6 per lb. | |
| 200 off | ... ... ... | £ 2.4 per lb. | |
| 500 off | ... ... ... | £ 2.28 per lb. | |
| 1000 off | ... ... ... | £ 2.24 per lb. | |

fully tooled up for production of less than about a dozen aircraft.

Actual production costs of existing aircraft have been spotted on the curve. They show that, in addition to the fact that American prototypes cost more than prototypes of equivalent size built in the United Kingdom, in line with the fact that more man-hours are expended on development work in the U.S.A., American production costs are, on the whole, also higher than their British counterparts. Severe losses on the part of American aircraft manufacturers engaged in the production of civil aircraft may influence this still further in the future—unless military orders change the whole economic position.

Returning again to the seven types of contemporary aircraft which I have selected for comparison, the basic facts which remain to be established, after costs, are:—

(*a*) the weights, and
(*b*) the performance.

Now here, and in what I have to say later, I must accept responsibility for the figures quoted, while acknowledging gratefully all the help received from both manufacturers and operators in compiling the data. In some respects, the figures I shall quote will be found to differ from the manufacturers' figures. The reason for this is that I have assumed that, in every instance, the aircraft have been in service for some time, and that they will, therefore, have lost some performance and have gained some weight, as inevitably happens even in the best regulated airlines and with the best made aircraft.

In addition I have assumed the incorporation of the miscellaneous assortment of equipment which an aeroplane always collects in commercial service. Consequently, the figures quoted may be considered somewhat pessimistic compared with those for a new and pristine aeroplane of each type. But, one of the cardinal sins of any economic analysis is wishful thinking.

### 4.2.3. Weights.

With these things in mind, Table VII sets out weight data for the seven types. These weights are as nearly factual as I can determine after careful checks of the average weighed amounts for such of the aircraft as are in service. Those for the Ambassador and the Brabazon I are estimates based on weights established from the prototypes. Those for the Orion are derived from experience of other types.

The weights show a steady decrease in the percentage of equipped weight empty as size increases throughout the range. The percentage of the equipped weight declines from 75 per cent. of the take-off weight at the small end, to 56 per cent. at the large end of the scale. This bears out in practical fact the contention of those who argue that the large aeroplane can always defeat the "square-cube law" and can be made more efficient in weight than can the small aeroplane. Thus, whereas the net disposable load of the Rapide is 26 per cent. of its gross weight, that of the Constellation is 37 per cent., and that of the Brabazon Ib is 44 per cent. These results, expressed in Fig. 2, are gained despite the more complex equipment in the larger aircraft. It is only fair to point out however that the larger types of transport aircraft are not usually required to operate from the relatively short runways used by the smaller types. The longer take-off run permitted to the bigger machines accounts, to some extent, for their improved percentage of disposable load.

The table of weights brings out a further point. The maximum usable fuel capacity has to be matched to the payload which can be carried in both the maximum range condition and with capacity payload. Too much fuel would mean such a small payload that the full fuel tankage could never be used economically. Hence weight would be wasted on unnecessary tanks. Similarly, too little tankage would mean a restriction on range which would result in inadequate regularity against headwinds. Inspection of the weights suggests that the normal 1,000 gallon tankage of the Ambassador is rather on the low side to make full use of the flexibility of the aeroplane. So in the version I have taken, I have assumed that the optional extra tanks are installed, increasing the maximum range substantially without reducing the payload to an uneconomic extent.

### 4.2.4. Performances.

The assumed figures for the performance of the seven types are set out in Table VIII. I must emphasise again that these characteristics are somewhat less than would be achieved from new aircraft. However, they are representative of operating performances from these types in everyday service.

Cruising speeds at full load vary from 120 m.p.h. for the Rapide up to 332 m.p.h. for the Brabazon I, at heights which range

## TABLE VII

| | | RAPIDE III | DOVE I | DAKOTA III | AMBASSADOR II | CONSTELLATION IV | ORION I | BRABAZON IB | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Structure weight. | 1830 | 2390 | 8830 | 18,280 | 27217 | 54,000 | 83,900 | 1 |
| 2 | Power plant & systems weight. | 1320 | 2160 | 5,620 | 11,090 | 18935 | 36,700 | 44,700 | 2 |
| 3 | Operating equipment weight. | 330 | 830 | 2340 | 2840 | 4240 | 8100 | 13,600 | 3 |
| 4 | Passenger equipment weight. | 270 | 440 | 1,740 | 3,230 | 8490 | 10,600 | 12,600 | 4 |
| 5 | Empty weight. | 3,750 | 5820 | 18530 | 35,440 | 59190 | 109,400 | 154,800 | 5 |
| 6 | Cockpit crew. | 400 | 400 | 600 | 600 | 1150 | 1150 | 2,300 | 6 |
| 7 | Cabin crew. | Nil. | Nil. | 200 | 200 | 400 | 600 | 1,000 | 7 |
| 8 | Fixed stores. | Nil. | Nil. | 250 | 460 | 2890 | 5500 | 5,600 | 8 |
| 9 | Unusable fuel. | 30 | 50 | 170 | 390 | 720 | 1,450 | 2,400 | 9 |
| 10 | Basic weight. | 4,180 | 6,270 | 19,750 | 37,090 | 64,350 | 118,100 | 166,100 | 10 |
| 11 | Maximum oil capacity. | 70 | 130 | 430 | 650 | 1640 | 3500 | 1,600 | 11 |
| 12 | Equipped weight. | 4,250 | 6,400 | 20,180 | 37 740 | 65,990 | 121,600 | 167,700 | 12 |
| 13 | Maximum usable fuel capacity. | 520 | 1160 | 4,750 | 11,120 | 34,200 | 73,880 | 111,000 | 13 |
| 14 | Corresponding payload. | 980 | 940 | 3120 | 3270 | 5,050 | 5,000 | 22,100 | 14 |
| 15 | Usable fuel with capacity payload. | 150 | Nil. | Nil. | 3250 | 25,510 | 53,880 | 105,900 | 15 |
| 16 | Capacity payload. | 1350 | 2100 | 7,870 | 11140 | 13,740 | 25,000 | 27,200 | 16 |
| 17 | Disposable load. | 1,500 | 2,100 | 7,870 | 14390 | 39,250 | 78,880 | 133,100 | 17 |
| 18 | Gross weight. | 5,750 | 8,500 | 28,050 | 52,130 | 105,240 | 200,480 | 300,800 | 18 |
| 19 | Pre-flight fuel allowances. | Negligible | Negligible | 50 | 130 | 240 | 480 | 800 | 19 |
| 20 | Maximum take-off weight. | 5,750 | 8,500 | 28,000 | 52,000 | 105,000 | 200,000 | 300,000 | 20 |
| 21 | Maximum landing weight. | 5,750 | 8,500 | 26,000 | 50 000 | 87,500 | 170,000 | 240,000 | 21 |

All weights in lb.

Weight Analysis—Selected Contemporary Aircraft.

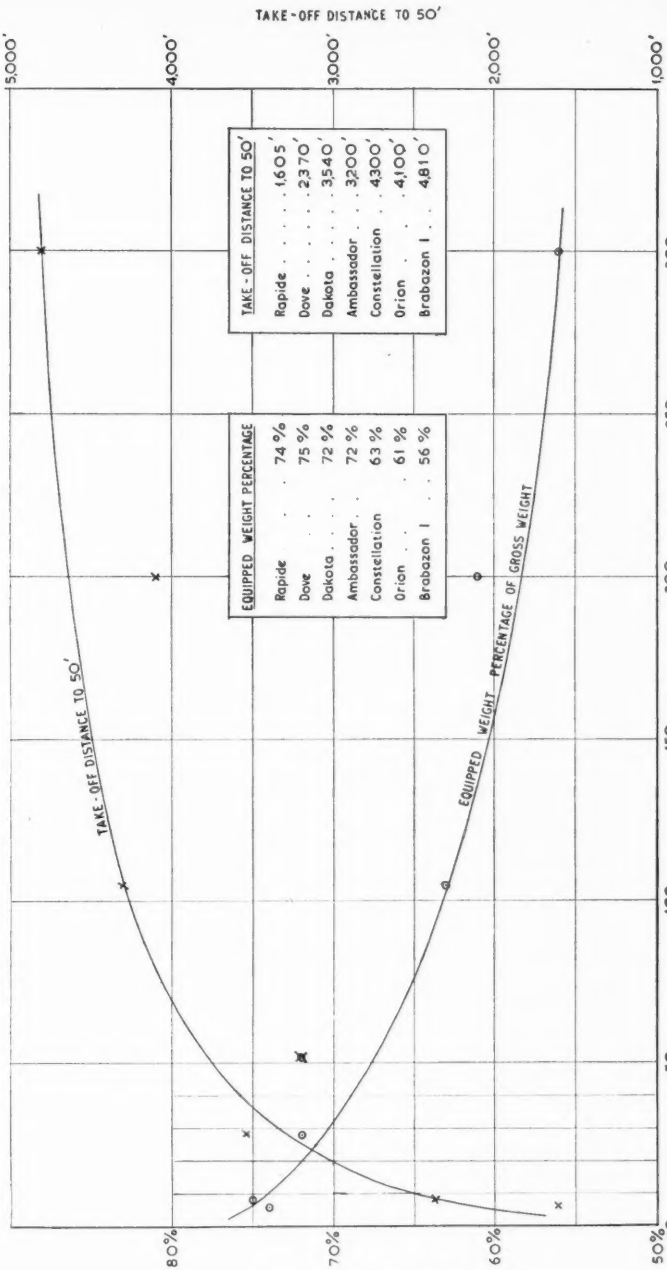


Fig. 2.
Equipped weight and take-off distance *v.* Gross weight.

from 2,000 ft. up to 38,000 ft., between the two extremes. The selected cruising powers (which are those normally used for the convenient constant-power cruise technique), range from 71.5 per cent. of METO* power (65.4 per cent. of take-off power) for the Rapide up to a mean of 55.7 per cent. of METO power (49.3 per cent. of take-off power at 97.5 per cent. of maximum r.p.m.) for the Brabazon IB. As the Brabazon is turbine powered, that latter figure represents a high percentage of the maximum power available to it at height. When the performance, powers and consumptions are related and expressed as air miles per gallon, the curve shown in Fig. 3 is found to be typical for these and other aircraft. The resulting theoretical still-air ranges at operating height vary from 515 statute miles for the Rapide up to 5,300 statute miles for the Brabazon I.

An interesting point is the take-off run required to achieve a height of 50 ft. on all engines at maximum gross weight. The shortest distance to 50 ft. is achieved by the Rapide with 1,605 ft. (535 yards).

Although, on estimates, the Brabazon requires the longest distance to reach 50 ft. at take-off, namely 4,810 ft. (1,603 yards), this distance is only some 12 per cent. longer than that required by the Constellation, which is always considered exceptionally good. With its eight engines, the safe length of runway required for the Brabazon IB will be approximately the same as that required by the Constellation—a remarkable achievement.

The Brabazon IB shows up as a most formidable commercial aeroplane, offering prospects of a performance unequalled in competitive aeroplanes. The economic analysis made later bears out this view—although technical and commercial success can be gained only as a result of unceasing effort for five or six years to come, and it is too early yet to do more than note the promise shown in so bold an enterprise.

All this means that runways about 6,150 ft. (2,050 yards) long will be adequate for any of the seven aircraft considered and that, contrary to some earlier, ill-informed comment, misled by the length of test runway required for the Brabazon I, the very big aeroplane comes well within present runway standards. With a four wheel undercarriage on each side, its demands on the bearing-strength of runways are also likely to be within present standards of first-class airports, without additional strengthening of surfaces.

Having thus established the basic characteristics for prime cost, weight and performance for the seven contemporary types, the next requirement is to apply these characteristics to operating conditions. That is where purely theoretical analyses are liable to prove so thoroughly unreliable. For instance, we often read of a certain payload required for such and such a "still-air range" and of two aircraft of widely varying characteristics being compared over similar still-air ranges. The trouble is that the still-air range of an aeroplane, although of considerable academic interest, is of little practical value because necessary allowances and reserves vary so widely for different types over different stages in different operating conditions.

For instance, to take two extreme examples, a jet aeroplane cruising at 500 m.p.h. for a theoretical still-air range of 3,000 miles, with no allowances, might, in particular circumstances, have a practical operating stage length, with allowances and diversion and stand-off reserves, of about 1,000 miles. On the same basis of allowances and reserves a similar aeroplane with, say, compounded piston engines with a similar 3,000 miles still-air range at 300 m.p.h. would have a practical operating stage length of some 1,900 miles; 90 per cent. better than the jet. The shocking thing is the extent to which allowances and reserves cut down the effective radius of action of the jet—and, indeed, of any commercial aeroplane—in the present state of air traffic control. These matters merit a detailed examination.

## 4.3. OPERATING STANDARDS.

### 4.3.1. GENERAL PRINCIPLES.

An unconscionable number of variables appear when an attempt is made to assess the operational performance of any aeroplane, old or new, over any particular route.

For instance, the actual and the maximum-permissible take-off weights will be affected by many factors—the amount of fuel and payload carried, the heat of the day, the height of the aerodrome, the length of runway, the safety standards adopted. The weight of the aeroplane will be varying from the moment the engines are started, as fuel is consumed. The cruising power and the cruising procedure used can be varied within wide limits, so that the consumption and the

* METO = Maximum except take-off.

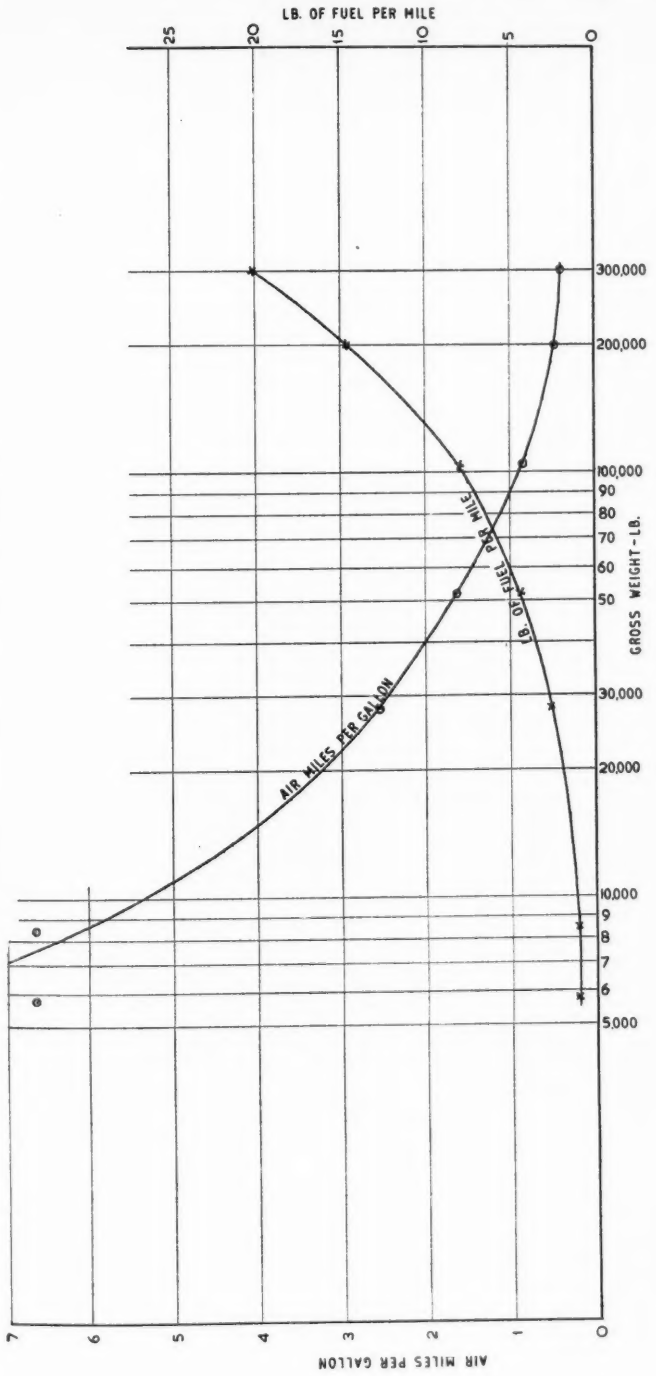


Fig. 3.

Fuel consumption versus Gross weight.

| *Air Miles per Gallon* | | *Lb. of Fuel per Mile* | |
|---|---|---|---|
| Rapide ... | 6.65 | Rapide ... | 1.06 |
| Dove ... | 6.64 | Dove ... | 1.06 |
| Dakota ... | 2.55 | Dakota ... | 2.70 |
| Ambassador ... | 1.62 | Ambassador ... | 4.35 |
| Constellation ... | 0.835 | Constellation ... | 7.90 |
| Orion ... | 0.470 | Orion ... | 14.50 |
| Brabazon I. ... | 0.394 | Brabazon I. ... | 20.10 |

## BASIC PERFORMANCE DATA (SEVEN CONTEMPORARY AIRCRAFT)

TABLE VIII

| | | Units | Rapide III | Dove I | Dakota III | Ambassador II | Constellation IV | Orion I | Brabazon I | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Total take-off power ... ... ... | e.h.p. | 406 | 690 | 2,400 | 5,400 | 10,000 | 20,000 | 28,000 | 1 |
| 2 | METO power ... ... ... ... ... | e.h.p. | 370 | 570 | 2,100 | 4,640 | 8,400 | 16,800 | 24,800 | 2 |
| 3 | Cruise power assumed (mean) ... ... | e.h.p. | 265 | 414 | 1,050 | 2,600 | 5,040 | 10,000 | 13,800 | 3 |
| 4 | Per cent. of METO power assumed for cruise | per cent. | 71·5 | 72·5 | 50 | 56 | 60 | 60 | 55·7 | 4 |
| 5 | Cruising height region (operating height at start of cruise regime) | feet | 2,000 | 8,000 | 8,000 | 20,000 | 20,000 | 20,000 | 28,000 | 5 |
| 6 | Cruising height region (operating height at end of cruise regime) | feet | 2,000 | 8,000 | 8,000 | 20,000 | 20,000 | 20,000 | 38,000 | 6 |
| 7 | Assumed average cruising fuel consumption (at operating height)... ... ... ... | lb./hour | 130 | 194 | 470 | 1,195 | 2,340 | 4,680 | 6,820* | 7 |
| 8 | Assumed specific cruising fuel consumption | lb./e.h.p./hour | 0·491 | 0·469 | 0·448 | 0·460 | 0·465 | 0·468 | 0·494* | 8 |
| 9 | Cruising speed at take-off weight... ... | m.p.h. | 120 | 179 | 166 | 270 | 279 | 305 | 332 | 9 |
| 10 | Cruising speed at 85 per cent. take-off weight | m.p.h. | 123 | 183 | 174 | 275 | 297 | 315 | 339 | 10 |
| 11 | Cruising speed at 70 per cent. take-off weight | m.p.h. | 126 | 187 | 178 | 280 | 307 | 339 | 339 | 11 |
| 12 | Cruising consumption at 85 per cent. take-off weight ... ... ... ... ... | lb./mile | 1·06 | 1·06 | 2·70 | 4·35 | 7·9 | 14·9 | 20·1 | 12 |
| 13 | Air miles per gallon ... ... ... ... | a.m.p.g. | 6·65 | 6·64 | 2·55 | 1·62 | 0·835 | 0·470 | 0·394 | 13 |
| 14 | Theoretical still-air range at operating height, no allowances ... ... ... | statute miles | 515 | 1,095 | 1,760 | 2,660 | 4,300 | 5,060 | 5,300 | 14 |
| 15 | Estimated take-off distance to reach 50 feet on full power at max. take-off weight ... | feet<br>yards | 1,605<br>535 | 2,370<br>790 | 3,540<br>1,180 | 3,200<br>1,067 | 4,300<br>1,433 | 4,100<br>1,367 | 4,810<br>1,603 | 15 |

* Assumed figures dependent on power plant development.

air miles per gallon will vary. The cruising height and, hence, the true air speed can be altered constantly. The influence of the wind is changing all the time. In addition the route flown can be varied. In the background are the subsidiary variables inherent in the aircraft type—such as its ability or relative inability to operate continuously under icing conditions and in turbulence, and the effect of these conditions on its operating speed.

With all these factors changing and interchanging, the establishment of precise performance factors is like hunting a will o' the wisp.

Nevertheless, amidst this mist of inconstancy, three main operating standards can be determined as applying to all commercial airline services in greater or lesser degree.

The first is *Reliability*
The second is *Regularity*
The third is *Punctuality.*

All three are interdependent. And in all three the chief operational factors to be contended with are low visibility and the wind. Indeed, not since the great days of sail—

*And the ships under topsails, beating, thrashing by*[51]

has any form of transport been so influenced by the winds. So long as the wind component remains an appreciable proportion of the normal cruising speed—that is to say, until we can cruise normally at 2,000 mp.h. or so —the wind effect will remain, and the regularity, punctuality and economy of an airline will be affected materially thereby.

Although the days have passed when the wind seriously affected reliability of operation, regularity on long trans-ocean flights is still the catspaw of the wind, while punctuality, even on short flights, can be seriously upset by a stiff breeze. In addition, the present inadequacies of air traffic control —which lead, in bad weather, to the stacking up of aircraft over their destination awaiting landing turn—have a serious influence on punctuality. Wind and weather, therefore, together constitute serious limitations on the swift expansion of air transport services economically.

Wind and weather are, unfortunately, outside the control of Air Transport operators. But a most important factor which can be adjusted and is the cause of serious delays at present is mechanical reliability. Much requires doing to improve mechanical reliability of civil aircraft in the present state of aeronautical development. At present a good and proven aeroplane operated over an average route will be delayed by mechanical trouble to a slightly less extent than by weather. But the average commercial aeroplane of to-day will suffer more mechanical than weather delays.

The setting out of precise standards among so many variables is both difficult and liable to be tedious. Nevertheless, such standards and a clear conception of them are essential, not only to a full understanding of the underlying problems of scheduled air transport operations, but also to the accurate forecasting of the practical possibilities of new aircraft.

So far as I am aware, no ordered philosophy applying to these desirable standards and to their consequential results has yet been set down, although Mr. Christopher Dykes and the late Captain R. G. Buck of B.O.A.C. have both made notable contributions to the fundamental thinking on this subject, and their pioneering work deserves to be more widely known and recognised. In the United States a valuable memorandum has been written on some aspects of the problem by Mr. Austen F. E. MacInerny and Mr. Edward Fife of the Lockheed Aircraft Corporation.

Even so, the philosophy of operating standards remains largely undefined, although it is of fundamental importance to Air Transport economics, particularly on long-stage routes, and will increase in importance as jet-propelled aircraft begin to appear.

The time, therefore, is more than ripe for an attempt at a statement of as comprehensive a theory on basic operating standards as is possible for a science which is developing so swiftly. With some temerity I shall attempt it here. The arguments and considerations which constitute this philosophy require stating, although their detail is not necessarily of interest to all who may read this Paper. I suggest to those who do not wish to go into the full detail that they should turn to the Summary on page 620.

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The standards required, as I have already said, are related to:—

Reliability, Regularity and Punctuality of operation.

*Reliability*, in the sense used here, can be defined as the degree of certainty of eventual arrival at the intended destination. Reliability must be absolute, because it is synonymous with safety. Once an aeroplane has set out on a flight, it must always arrive



* Assumed figures dependent on power plant development.

—either at its destination, or, in the worst possible conditions, either at a designated alternative airport, or back at its starting point. Nothing short of 100 per cent. reliability—and, hence, safety—can be permissible as a target.

*Regularity* in Air Transport can be defined as the percentage of occasions on which a flight is started, within an arbitrarily selected time of the advertised departure, compared with the number of starts scheduled to be made. Regularity cannot be absolute, especially on long-stage routes where the range of an aeroplane is stretched to the limit in the present state of aircraft development. A compromise has to be reached between the conflicting economic effects of a postponement of a departure (and the consequent dislocation of services) or of starting in conditions which demand other economic sacrifices—such as payload for extra fuel—in order to maintain absolute reliability of arrival. In practice a "target regularity" of not less than 90 per cent. during the worst season (say 95 per cent. throughout the year) has been found to be a minimum which can be accepted if satisfactory schedules are to be maintained. That means that cancellation or serious starting delay cannot be tolerated on more than about one service in ten—and then only in the worst season. Often a higher regularity is possible. The standard which can be achieved will vary with the weather experienced in different parts of the World, as well as with the density of the local air traffic.

*Punctuality* is really an extension of regularity and, like regularity, cannot be absolute. Even the railways have found this after 123 years of operation. Air Transport, three generations younger, is acutely aware of the fact. Just where unpunctuality ceases to be unpunctuality in relation to the advertised timetable and becomes irregularity of operation is one of those intangibles which can be settled only arbitrarily. Certainly punctuality is relative. An arrival half an hour late after a 50 hour journey from Australia is of less consequence than would be a 20 minute delay after an hour's flight from Paris. Certainly the most difficult operations on which to maintain punctuality are long, non-stop, services such as across the North Atlantic, over which very strong wind components are encountered. Thus the degree of punctuality which can be aimed at will vary from route to route.

A precise standard of punctuality, applicable to all routes, cannot be stated because the degree of punctuality or unpunctuality will depend on the relative speeds of aircraft and wind, and on the length of stage. But the general statement can be made that the aim should be to arrive early rather than late on advertised times, so that the inevitable delays which cannot be foreseen will tend to improve rather than detract from punctuality. A careful examination of the economic factors suggests that time tables based on the head wind which will not be exceeded on 65 per cent. of occasions will afford the least unsatisfactory compromise between early and late arrivals, and will give a theoretical absolute punctuality on some 45 per cent. of occasions and "near punctuality" on at least 20 per cent. more—the precise degree depending on the length of stage. The low figure of the "65 per cent. wind" is acceptable only because of the hidden margins which are included in other operating standards and tend to raise the level of punctuality achieved above the theoretical.

These brief explanations of the standards to be sought for civil airline operations under the heads of Reliability, Regularity and Punctuality, serve to illuminate the complexity of the subject; beset as it is by many variables. The variables include not only those I have enumerated already but, also, in other contexts, additional influences as a result of fog, ice, snow, runway congestion, inadequate air traffic control, and the degree of mechanical reliability of the various airframes, engines and their numerous ancillaries. Nor should human fallibility be forgotten.

All these latter influences on the desirable operating standards are superimposed factors of irregularity and delay, against which direct action must be taken to improve navigational aids, to simplify procedures, and to improve maintenance characteristics. As such, they are outside the purview of this section of the operational theory, which is concerned rather with operational standards on which route planning can be founded.

When we examine the basis on which the required degrees of Reliability (100 per cent.), Regularity (minimum of 95 per cent.), and Punctuality, can be achieved, we find at once that the predominant requirement is sufficient fuel to cover all contingencies.

The essence of reliability of arrival is that the aeroplane shall continue to fly until it

reaches its destination, or an alternative airport. Obviously, an aeroplane can remain flying only so long as it has fuel. Therefore:

(*a*) It must have fuel tankage adequate for the route conditions, and

(*b*) Before a flight begins, enough fuel must be put into the tanks to ensure that the aeroplane can continue flying until its destination, or an alternative, is reached —in all foreseeable circumstances against which application of the "theory of probabilities" shows reason for provision.

If these conditions are fulfilled, reliability will be absolute, apart from mechanical or human failure, or some catastrophic intervention of nature.

Fuel reserves and allowances must be adequate to meet all calls upon range and duration over the particular route once a flight has been started. Reliability here is closely bound up with regularity. For instance, with the fuel tankage available there might be certain days on which the head wind component over the route was such that the aeroplane could not carry enough fuel to complete the flight, regardless of payload. Regularity of starting would then have to be sacrificed to ensure that the record for absolute reliability of arrival was not impaired.

Carrying this a stage further; although services must be operated only when reliability of arrival can be guaranteed, for a particular stage at a specific regularity the tankage required might have to be sufficient for flight on, say, 85 out of the 90 worst consecutive days of the year—that is against a head wind component which is not exceeded on 95 per cent. of occasions in the worst season.

*Thus,*

Regularity of departure, and with it, Punctuality, should be maintained subject only to the over-riding requirements of Reliability of Arrival.

Whatever the circumstances, Reliability of Arrival must be maintained, even at the expense of postponing a service.

This leads us to the subject of fuel allowances and reserves.

4.3.2. FUEL ALLOWANCES AND RESERVES.

From the manufacturer's sales angle the factor in estimates of operating performance which is most often under-rated is that of fuel allowances and reserves. Fuel "sterilised" for these purposes cuts uncomfortably into the available payload. There is a temptation to underestimate allowances and reserves when advertising payload for new aircraft. But fuel allowances and reserves cannot be whittled away without a sacrifice in safety and reliability.

"Allowances" may be defined as the extra-to-cruising fuel needed for taxi, take-off, climb and descent; "reserves," as the extra-to-cruising fuel required at the end of a flight, against the need for diversion and stand-off.

Here it is important to be clear on definitions. The total fuel in an aeroplane at the start of a flight can be considered as having four components:—

(i) *Residual Fuel.*—This is the trapped fuel in the pipes and engines—the fuel which cannot be drained. Residual fuel is, therefore, included in the empty weight of the aeroplane. It is a *manufacturer's* figure.

(ii) *Unusable Fuel.*—This is the fuel which can be drained off when required but cannot be used to run the engines, even in favourable circumstances, because of the danger of engine cuts. It varies with design of sumps and with the consumption of the engines. As a generalisation, it amounts to about two gallons per tank, or about 100 lb. on a large aeroplane. It also is a *manufacturer's* figure. For convenience the unusable fuel is usually included with the fuel remaining, which is defined below. The total will then be substantially increased.

(iii) *Usable Fuel.*—This is the normal amount of fuel which can be burned in operation including all allowances and reserves.

(iv) *Fuel Remaining in Tanks.*—This is an operator's "hidden" reserve (*i.e.*, not normally counted in usable fuel). It is necessary to cover the effects of turbulence or gentle turns in the approach, which would cause "slopping," and also to allow for the inaccuracy of gauges. This is an *operator's* figure.

Fuel allowances and reserves may be considered as being of two kinds; those for mileage, and those for duration.

Mileage "allowances" comprise the amount of fuel needed for the distance covered while climbing to, and descending from, operating height. Mileage "reserves" allow for diversion to alternative landing fields when a landing at the intended terminal is impossible.

Duration "allowances" are those necessary to leave an adequate margin of fuel in the tanks for circuit, approach, landing and taxi-ing. Duration "reserves" allow for the aeroplane to be "held" outside or above the

circuit, awaiting its landing turn. A further duration "reserve" is the "fuel remaining," the operator's margin to prevent the possibility of engines cutting should the tanks be run too low. This "duration reserve," for convenience, can be bracketed with the "unusable fuel," which is the amount of fuel specified by the manufacturers as being a necessary minimum remainder in the tanks to provide a reliable fuel supply. These two items—"fuel remaining" and "unusable fuel" —may be lumped together and subtracted from the tankage capacity to give a figure for "maximum usable tankage."

Whereas the *mileage* allowances and reserves are hard on the slow aeroplane, particularly against a head wind, the *duration* allowances and reserves are critical for the fast jet types to which we look in the future.

The total usable tankage required can be said to be the sum of the amount of fuel required for four separate regimes in any operation:—

1. PRE-FLIGHT ALLOWANCES.
   Fuel required for
   (*a*) Starting,
   (*b*) Taxi-ing out, and
   (*c*) Engine checks at end of runway.
2. FLIGHT ALLOWANCES.
   Fuel required for
   (*a*) Take-off,
   (*b*) Climb to operating height,
   (*c*) Descent from operating height,
   (*d*) Final circuit,
   (*e*) Approach and landing, and
   (*f*) Taxi-ing in—this may strictly be assumed to come out of the "fuel remaining."
3. RESERVES.
   Fuel required for
   (*a*) Flight to alternative airport,
   (*b*) Stand-off over destination or alternative airport.
4. CRUISING CONSUMPTION.
   Fuel required for
   (*a*) Normal cruise in prevailing wind at operating height (plus appropriate allowances for more adverse winds than those flight planned).

In addition, allowance should be made for:—

(*a*) Engine maladjustment,
(*b*) Airframe deterioration,
(*c*) Navigational deviation,

all factors which will inevitably occur and will reduce the performance of the aeroplane below that theoretically possible—although application of the "theory of probabilities" will mean that the full amounts need not be included under all three heads at the same time.

Parallel with the fuel allowances, which influence the tankage and payload, there are also the time allowances, which influence the time required to cover any specific stage.

Time allowances can be subdivided into the following components:—

(*a*) Time taxi-ing out.
(*b*) Time on engine checks.
(*c*) Time to take-off.
(*d*) Time to climb to operating height.
(*e*) Time on descent.
(*f*) Time on final circuit.
(*g*) Time on approach and landing.
(*h*) Time taxi-ing in.

These time allowances, during some of which some of the *en route* distance is covered, vary between about 15 minutes and about 2 hours 30 minutes, according to the type of aeroplane, while the distance covered on course during climb and descent may vary between about 10 miles and about 600 miles, according to aircraft and operating height.

I shall return to all these points in further detail in the analysis of requirements for particular types of aircraft, later in this Paper.

Having established the basis from which there can be determined either the tankage required for a new aeroplane, or the routes over which an existing aeroplane could be operated, the next step is to discover the factors which will set the amounts of fuel required for scheduled operations at the required regularity.

We must not lose sight of the fact that, whatever the regularity, the main objective of an airline is to carry as much payload as possible over the route at the highest frequency which the traffic will bear. Thus, any estimate of the performance characteristics and of the economic possibilities of an aeroplane flying on a particular route must be founded on:—

(*a*) An established average payload carried per trip, throughout the year,
(*b*) A calculated average block-to-block speed over the route throughout the same period, and
(*c*) An estimated annual figure for the amount of fuel consumed.

An analysis of these three factors, in terms of the operating standards I have discussed, brings up the problem of advanced payload

booking and the influence of passenger "load factor"—the percentage of seats filled to seats offered—on the practical results.

These matters are so important to the whole question of operating standards that they must be discussed in some detail in order to bring out their full implications on aircraft requirements. The problem is to determine, months ahead, the maximum payloads which can be offered for sale on a route in the light of the headwinds which must be anticipated and the regularity desired.

4.3.3. THE PHILOSOPHY OF THE "BOOKING PAYLOAD."

From an operating point of view, the traffic department of an airline must know in advance what payloads it can safely offer for sale on a particular route on a particular day—regardless of wind or weather. If too much space is sold, either some booked payload will have to be off-loaded—which is not commercially permissible—or the amount of fuel which can be taken on board will have to be restricted. If fuel is restricted then, when strong headwinds are forecast in the flight plan, the aeroplane may not be able to take off. Regularity will have to be sacrificed to maintain safety.

Conversely, if too severe a restriction were placed on the amount of payload which could be offered for sale in advance and, on the day, the winds were no more than average, then the aeroplane would leave half empty, sacrificing revenue and hence economy.

For these reasons, the calculations of the maximum payload which can be booked in advance are extremely critical.

Either over-selling or under-selling of space will be equally unsatisfactory.

That is where the interacting philosophies of "booking payload" and of "target regularity" come into play.

First of all the definitions:—

*The Booking Payload* is the payload which can be sold months ahead for a particular type of aeroplane flying on a particular route. The "booking payload" may be varied with the time of year on certain routes to meet fluctuation in winds and traffic.

*The Target Regularity* is the minimum regularity of take-off which can be accepted for satisfactory scheduled operation. A figure of 95 per cent. in the worst season has been taken as a reasonable objective.

On this basis, two factors must be considered. First, the maximum wind component which will have to be encountered in

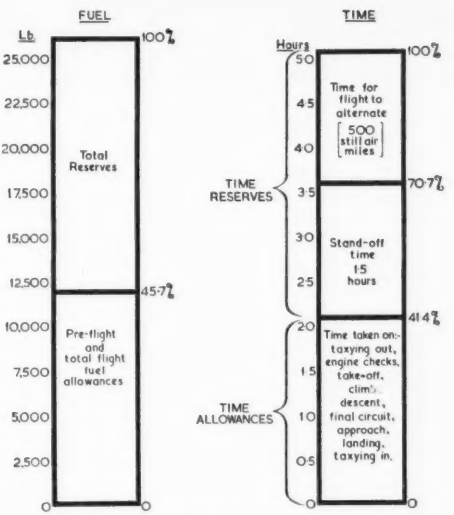


TABLE IX

Typical total allowances and reserves—Orion I.

achieving the desired regularity of 95 per cent. in the worst season. The maximum wind not exceeded on 85 days out of the 90 worst consecutive days will have to be allowed for. In conjunction with the fuel allowances and reserves, it will dictate the aeroplane's maximum tankage when a new design is being planned for a particular route. Conversely, with existing aircraft, it will decide the stage lengths which are operationally possible.

The first factor is thus the "95 per cent. worst season wind" which sets the tankage. This should also provide for the lowest acceptable seasonal regularity, which for any specific stage and height will bear a fixed relationship to the regularity which can be achieved throughout the year. The second factor is the wind which dictates the booking payload.

I have assumed here that the average booking payload throughout the year will be governed by the most adverse equivalent wind component which will occur at operating height on up to 85 per cent. of occasions during the worst three months of the year—that is the headwind component which is not exceeded on 77 out of the worst consecutive 90 days in a year. (The booking payload for straight jet aircraft will probably have to be based on a somewhat higher wind.) The weight available for payload when the total

fuel required for these conditions has been taken aboard, is the booking payload and assumes 100 per cent. load factor. It is the payload beyond which the traffic office cannot sell.

With piston-engined aircraft the "85 per cent. worst season wind" gives a fairly typical figure for booking payload which is suitable for a general analysis. But it achieves this at the expense of a rather low *apparent* regularity in the worst season (85 per cent.). Here the apparent regularity and the actual regularity must not be confused. There is more flexibility in operation than has so far been suggested.

The variables are such that eleven points modify the apparent regularity and influence the actual regularity achieved. They are:—

(*a*) The effects of cruising procedure on the payload/range characteristics of the aeroplane.

(*b*) Fluctuations in traffic in relation to frequency—influencing the fuel load which can be carried.

(*c*) The effect of passenger load factor on booking payload—again modifying the fuel load.

(*d*) Possible variation in cruising height to gain more favourable winds on particular occasions.

(*e*) The influence of navigational techniques on effective route winds, particularly the development of "pressure pattern" navigation, which alters the shape of the "effective headwind probability curve."

(*f*) The effect of mechanical unreliability—both of the aircraft and of ground services, such as radio aids.

(*g*) Meteorological influences, other than wind, which cause delays or diversions, *e.g.*, fog, ice, snow on runways, and so on.

(*h*) Traffic congestion in the circuit, causing delays or diversions.

(*i*) The distance which has to be covered to the alternates and the possibilities of route diversion.

(*j*) The human element and the allowances which have to be made for variation in operating performance on the part of air crews.

(*k*) The number of landings made during a given utilisation—(each landing increases the possibility of delays).

Let us examine these in more detail.

Variations in cruising procedure can be used to gain superior results in range and payload in different conditions of wind, hence improving regularity. For instance, a high percentage of cruising power is useful against a strong headwind because it will reduce the time over which the headwind can take effect. It has been found, in practice, that if possible the true air speed should be increased by 25 per cent. of the headwind component to give the most economic results. Similarly, "long-range cruise" procedure, under which the power is continually reduced as fuel is burned and the weight lightened, will prolong the duration of the aeroplane materially. In light winds, or under the influence of tail winds, "long-range-cruise" procedure can effect useful economies. Thus the cruising procedure adopted can have a marked influence on results—in payload, in range, and in regularity, as well as in adherence to, or divergence from, the scheduled times.

The booking payload can be allowed to change over different seasons in sympathy with fluctuations of seasonal traffic demands and with varied frequencies. As a result, a lower booking payload may be feasible in the most adverse season, and in consequence an improved seasonal regularity may be possible.

Examples of seasonal fluctuation of traffic and frequency which bear out this point are shown in Figs. 4 and 5.

Although the "85 per cent. wind" in the worst season has been taken as governing the booking payload, this assumption does not mean that the achieved regularity will remain fixed at 85 per cent., even without a change in the booking payload. To prevent uneconomic traffic "stack ups," the total payload capacity provided on the route should be related to the traffic offering so that the load factor is of the order of 65 per cent. The annual capacity will be governed by the frequency provided and by the available payload, both of which, in their turn, will determine the number of aircraft required on the route at an assumed utilisation.

The booking payload is equivalent to 100 per cent. load factor. The fluctuation of the achieved load factor round the average figure of 65 per cent. will provide space available for additional fuel on most occasions. The bonus on fuel, made possible by the amount by which the payload falls short of 100 per cent., will be reflected in improved regularity.

Thus, in practice, the apparent worst-season regularity (85 per cent.) will be considerably exceeded. For instance, if a booking payload on a certain route is

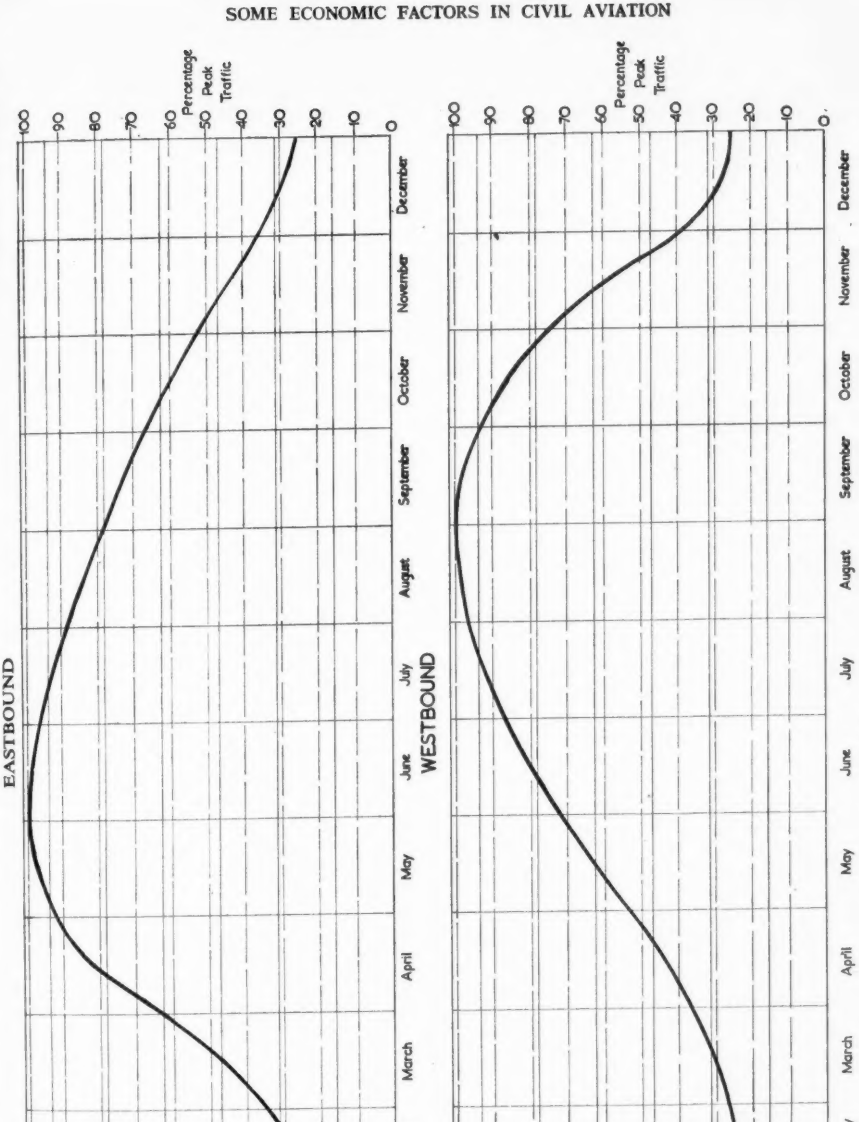


Fig. 4.
North Atlantic Route, U.K.-U.S.A., seasonal fluctuation of traffic intensity.
Passenger Units:—Based on 1946-47 figures, 1 Unit = 1,000 Passengers.

10,000 lb. and the traffic office has sold only 6,500 lb. at "closing time," then 3,500 lb. of disposable load are available to be used in the form of additional fuel, making possible operation against a higher head wind with a consequent increase in regularity.

Typical distributions of wind frequency at a selected operating height are shown graphically in Fig. 6 for a particular stage. This chart indicates that, for this individual case, the headwind component not exceeded on 85 per cent. of occasions during the worst season, on which the booking payload is based, is of the order of 70 m.p.h. On the other hand, the headwind component not exceeded on 95 per cent. of occasions during the worst season on which the tankage must be based, is of the order of 85 m.p.h.—the speeds being taken at 20,000 feet for the particular route.

Booking payloads calculated against an "85 per cent. wind" in the worst season might result, in a particular case, in an achieved regularity of perhaps 97 per cent. over the whole year after the effect of load factor had been applied. That is to say, the influence of the wind on regularity would be reduced to such an extent that normal operations should be possible on all except about five days during the worst three months of the year (95 per cent. achieved regularity in the worst season) and on perhaps another five days in the remaining nine months. The ratio of stage length and payload to the absolute stage of the aeroplane is the deciding factor on whether the regularity sought can be achieved.

Because some divergence from the normal cruising height is often acceptable, and because it may be possible to choose a cruising level at which there is a more favourable wind, regularity can often be improved still further so long as conditions, such as icing, permit.

Navigational techniques are yet another factor which can have an important influence on range, payload and regularity. The development of "pressure pattern" flying, in particular, is likely to lead to revision of some existing ideas. This comparatively undeveloped technique is potentially so important that I have dealt with it in some detail later in this review.

The effect on regularity of mechanical unreliability must not be forgotten. Delays caused by mechanical faults are lamentably frequent at present—the complexity of the large modern transport aeroplane is such that there are a large variety of individual systems liable to failure.* Such failures tend to cut down both the regularity and the punctuality achieved, well below the theoretical level. An interesting point is that such failures are almost directly related to the number of landings—an aeroplane performs adequately so long as it is in the air, but goes unserviceable as soon as it lands and the tinkering begins.

There are also meteorological influences—fog, ice and snow—which further cut into regularity. Added to them are the problems of traffic congestion in the circuit, and delays and imperfections in air traffic control. Regularity is affected also by the number of aircraft in the circuit—the fewer the aircraft, the less the problem. This is a powerful argument for large aircraft so as to keep congestion within limits—indeed as traffic grows, so must the size of aircraft grow also.

Distance to be covered to alternative aerodromes naturally determines the amount of reserve fuel needed. Similarly if, on occasion, a route diversion can be made, in order to shorten the stage length at the expense of an increased number of stages, both regularity and payload will be improved.

Also, the human element cannot be ignored. Inevitably different crews will attain different levels of efficiency, resulting in slightly different performances over a given route in particular conditions. This may be seen in variations in consumption of the engines, in navigational deviations and in the times taken for instrument "let down." Aircraft are constantly growing more complex, but human capacity remains the same. There is a tendency to load crews with more and more responsibility and, while all is well in good conditions, if things start going wrong in bad weather at the end of a long flight when the crew may be fatigued, there is not a wide margin left between required and possible performance on the part of the human element. A move towards simplification is now not only desirable but necessary in the interests of both regularity and reliability. Automatic approach and landing procedure, in which the crew will monitor the operation and act as emergency operators, instead of doing the whole job themselves, is a

* As an example of increased complexity the number of sparking plugs in a well-known "vintage" civil aeroplane is 56 compared with 224 in a modern successor. Turbine transports will improve this particular feature.

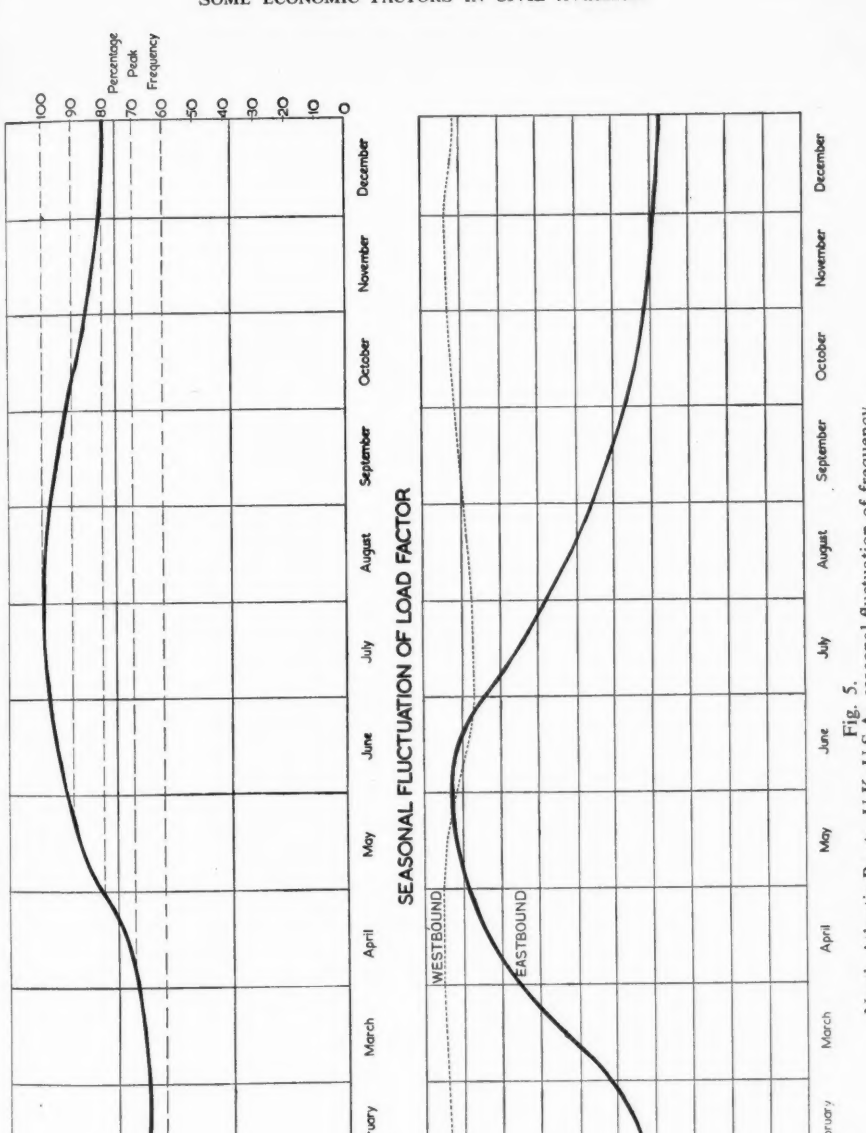


Fig. 5.
North Atlantic Route, U.K.-U.S.A., seasonal fluctuation of frequency.
Frequency Units:—Based on 1946-47 figures, 1 Unit = 1 Flight per Month.

requirement which deserves all the attention it can get.

Even so, regularity will be influenced by the number of landings made. Each landing increases traffic congestion and offers possibilities of delays from weather, mechanical trouble, or such like. The fewer the landings, the less cause there will be for irregularity, as a result of ground or meteorological influences. On the other hand, the longer the stages the more likelihood of delays if the aeroplane has marginal range for the route conditions.

Such are the chief factors which influence practical regularity on a route. One of them requires some further comment because its development may modify to a marked extent the range and payloads, and hence the regularities which may be achieved on long and difficult stages. I refer to "pressure pattern" flying.

4.3.4. "PRESSURE PATTERN" POSSIBILITIES.

By "pressure pattern" flying, the booking payloads, the time tables and even the maximum tankage requirements of a

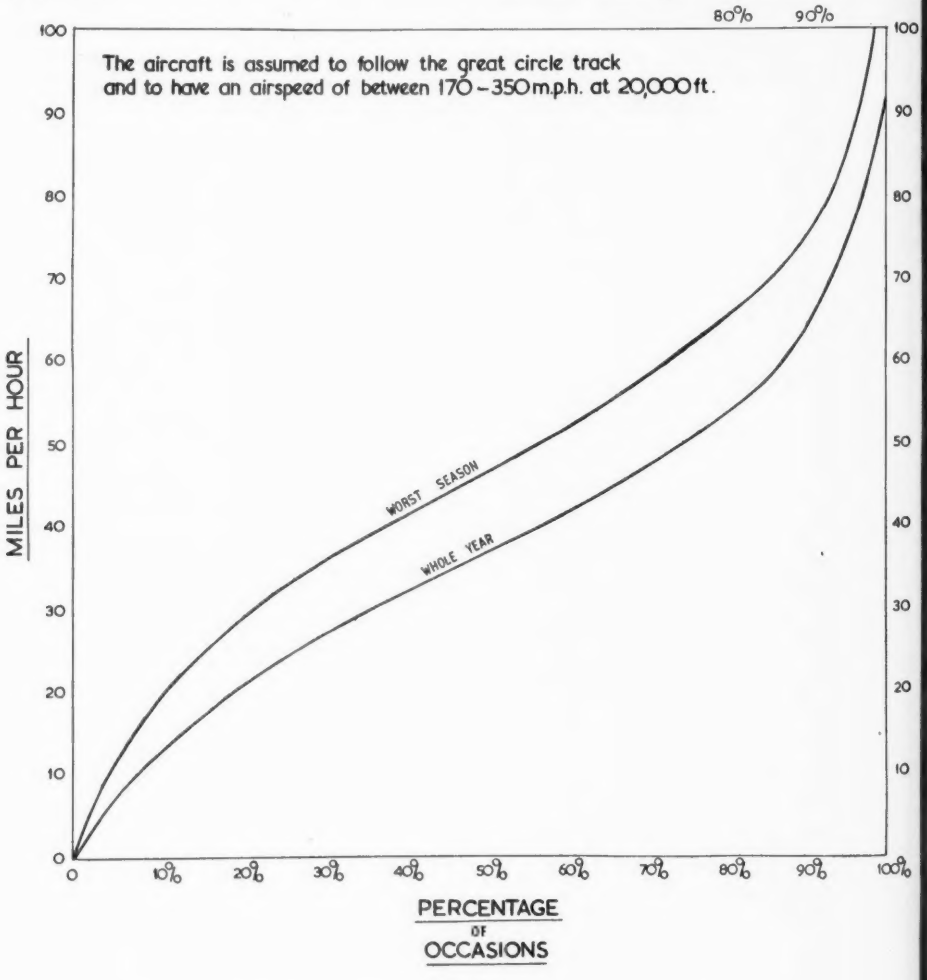


Fig. 6.
Typical distribution of equivalent route winds at 20,000 ft.

particular aeroplane on a specific route may well be adjusted in the future to lower effective route head winds than those prevailing on the great circle track.

The winds shown on the "wind frequency chart" (Fig. 6) are those prevailing on the great circle track of a particular stage. In the past these winds have governed payload, schedules and regularity and have been used for route analyses. Recent applications of methods of pressure pattern navigation to airline operations on long stage routes have required some modification of this basic approach, because deviations from the great circle may result in lower adverse winds or higher tailwinds being encountered. Although more geographical miles may be covered, less air miles will be flown. It is really the application of the technique of the "trade winds" to the air.

In effect this means that Fig. 6 may be redrawn to show "equivalent great circle route headwinds." These are the wind components which may be considered as prevailing over the great circle track which would give the same times of flight on that track as those actually experienced on the longer track dictated by the pressure pattern technique.

Figure 6, redrawn for equivalent great circle route headwinds, will then show less adverse wind components over the whole range of their frequency of occurrence. This may make possible a higher frequency for a given utilisation, a larger booking payload, faster schedules and less fuel for a given regularity. In time it may even mean that shorter ranges will be acceptable for a given route.

For this generalised examination of operating standards, the same arguments apply whether the calculations are based on the route winds or on the equivalent great circle route winds. With the former, great circle operation of each stage is assumed; with the latter, pressure pattern navigation is necessary.

At present there is probably insufficient statistical information on pressure pattern operation on any route for planning to go forward on the assumption of its general application. Nevertheless, there are likely to be important developments in this direction in the future.

4.3.5. Rapid Approximation of Range. Whatever the technique adopted, the approach will be the same. Once the required regularity has been agreed and the effective wind determined, the booking payload must be calculated.

By way of an example of the application of the theory of the booking payload and the target regularity to a particular case, a simplified approach is shown in Figs. 7 and 8. ("Stage Length Rapid Calculation Curves.")

Although these graphs are not suitable for obtaining more than an approximation, because they cannot take into account the influence of wind on the allowance for climb and descent, and do not provide for variations in mean cruising weight of the aeroplane, they do make possible the gaining of a quick indication of tankage required for any aeroplane over any stage length in any wind. The error for the headwind case will be to underrate somewhat the tankage required.

For instance, assume that a hypothetical aeroplane has a mean cruising speed of 280 m.p.h. and has to complete a stage-length-plus-alternate-distance of 3,000 miles against an "85 per cent. worst season wind" of 70 m.p.h. (Fig. 6). Turning to Fig. 7, the "wind versus cruising speed" chart, we find a co-efficient of 0.75 for a headwind of 70 m.p.h. encountered by a 280 m.p.h. aeroplane. The coefficient of 0.75 applied to the 3,000 miles stage-length-plus-alternate-distance in Fig. 8 gives an equivalent still-air range of 4,000 miles. That is the still-air range for which the tanks must be filled for the geographical distance. An additional amount of fuel is needed to cover the allowances and reserves. Let us assume that this amounts to the equivalent of a further 800 miles still-air range—a typical figure for a large aeroplane. If for this still-air range of 4,800 miles, the payload is, say, 10,000 lb. (Fig. 9), that will be the booking payload. Let us assume also that the traffic office sells only 65 per cent. of the payload, giving a 65 per cent. load factor. Then the fuel load can be increased by the amount by which the sold payload falls short of the booking payload.

Examining the hypothetical payload/still-air range chart (Fig. 9) for the equally hypothetical aeroplane, we find that for a payload of 6,500 lb., the still-air range is 5,100 miles. When the 800 miles for reserves and allowances is subtracted from this still-air range, the resulting equivalent still-air range is 4,300 miles.

Setting the 4,300 miles on Fig. 8, we find that, for the 3,000 mile stage, plus alternate requirement, the co-efficient is 0.7. Then, moving to Fig. 7, the "wind versus cruising

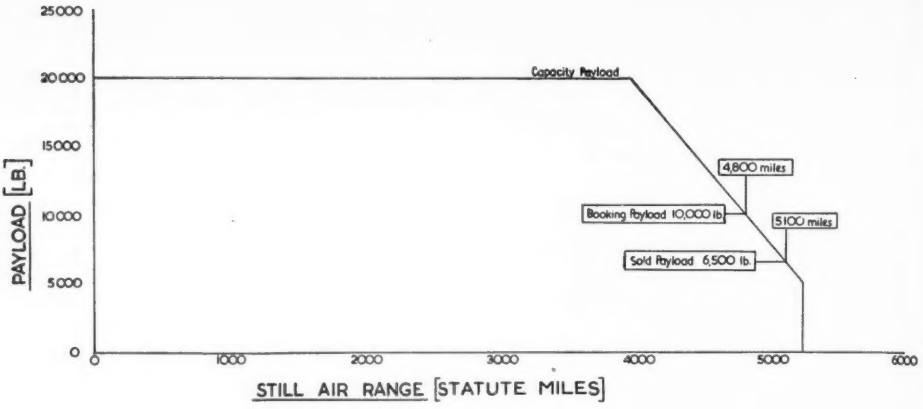


Fig. 9.
Typical payload/range chart.

speed" chart shows us that for a coefficient of 0.7, and for a 280 m.p.h. aeroplane, the headwind component can be 84 m.p.h. The "wind frequency" chart (Fig. 6) shows us that this wind of 84 m.p.h. represents a scheduled regularity of 94 per cent. in the worst season.

The practical meaning of this is that for this hypothetical condition, whereas the 85 per cent. regularity figure represents a booking payload of 10,000 lb., a sold payload of 6,500 lb. would represent the higher regularity of 94 per cent. in the worst season. Using this information in reverse, it means that in a peak season, if the flight plans showed that winds would permit reduced fuel, then additional bookings could be accepted above the booking payload, so that the extra traffic offering could be accepted while maintaining the same regularity. The important thing is to have big enough tanks for every fuel requirement to be met with at the 95 per cent. worst-season regularity for the particular route and stage length and, for economy, to be able to carry a reasonable payload at the required regularity.

In all these ways a desired operating standard of reliability and regularity can be achieved in conjunction with a booking payload set months in advance, provided that the aeroplane is adequate for the route.

The next point is to assess the degree of punctuality likely to be possible of achievement.

4.3.6. PUNCTUALITY POINTS.

Punctuality of both arrival and departure is as desirable in Air Transport as in any other form of locomotion. Punctuality of departure is largely governed by the availability of the vehicle at the starting point. That, in its turn, depends on a reasonable period for "turn round" between actual arrival time and the planned time of departure.

Here a distinction must be made between the average journey time actually achieved throughout the year and the time table journey time. The former is a firm figure which arises in fact. The latter is an arbitrary "guesstimate."

Punctuality of arrival is relative only to this, purely arbitrary, advertised arrival time set out in the published time table.

The "advertised arrival time" will bear a direct relationship to the average time of arrival achieved in the prevailing conditions. That relationship between the scheduled time of arrival and the achieved time of arrival can, within limits, be what the airline chooses to make it, because the time table will be precisely accurate for only one set of conditions and only one wind case on the route.

If the airline wished to convey an impression of higher speed over a route than its competitors, it could base its time table on lower adverse winds than average. The shorter journey time would look impressive, but the airline would gain a reputation for late arrivals.

Similarly, if the time table were set on higher than average winds, the competitive journey times would appear longer, but the airline would gain an improved reputation for punctuality.

The time table is thus influenced by commercial factors, whereas the achieved average time of arrival will depend entirely on the average route conditions.

Both the scheduled times of arrival and departure and the achieved times are important in different ways.

The average achieved journey time will determine the block speed made good throughout the year, and will thus have a direct influence on annual costs of operation (proportional to annual hours flown).

The scheduled departure times, which depend on reasonable punctuality of arrival, and also on a convenient time of departure (passengers will not embark cheerfully between say 2.0 a.m. and 5.0 a.m.) combined with the journey time, define the number of journeys made in a year, and will thus have a direct bearing on annual revenue (proportional to annual miles covered). In other words, the scheduled time for a round trip —which is the frequency—determines the revenue potential.

Revenue payloads—be they passenger or freight—are extremely sensitive to the degree of punctuality on which they can rely. Although late arrivals are unsatisfactory from all points of view, early arrivals are almost equally unsatisfactory to passengers. Arrivals *on time, all the time,* are the ideal, and time tables have, obviously, to be constructed so that achieved times will match published times as closely as possible.

Unfortunately, absolute punctuality must remain more of an ideal than a practical possibility for Air Transport for some time to come—especially on long routes.

For instance, between London and New York, a jet-propelled aeroplane cruising at an even 500 m.p.h. would have uncontrollable fluctuations in time of arrival amounting to about 80 minutes, solely because of the wide fluctuations in the wind from day to day. This 80-minute fluctuation in arrival time would represent a variation of about 17 per cent. in the total flight time. To achieve time table punctuality by variation of air speed alone would require an extremely flexible cruising performance—from say 435 m.p.h. to about 510 m.p.h.—which, although within sight as a possible variation in air speed, would, if attempted, probably so influence the range as to make it impractical as a cruising performance as well as being uneconomical.

Developments in pressure pattern navigation may well have as important an influence on this problem in the future as they will have on other operating standards. The prospects of reducing the present dominant influence of wind may therefore appear brighter in the future than they do at present.

Although the time table schedule can be set at any journey speed which seems desirable from the many conflicting points of view, it must be remembered that the aeroplane, cruising at normal power at a selected height can be on time against one wind speed only. As winds tend to "bunch" around the average, the selected "time table wind" should, obviously, be close to the average wind. In practice, by "throttling back" or "opening up," arrivals on scheduled time can be achieved not only against the exact "time table wind," but also over a "spread" of winds above and below that on which the time table has been set.

The problem is to choose that "time table wind" which will give the most economic results.

Although to be early is almost as unpopular as being late, it is certainly better, psychologically, to be early on more occasions than to be late. From the point of view of airline economy, aircraft maintenance, and provision for contingent delays, early arrivals have obvious advantages.

At first sight one might suppose that the average wind, that is the wind which blows on 50 per cent. of occasions (or the average wind which blows on the 95 per cent. of occasions on which operations are planned to be undertaken) would be the wind on which economic calculations should be based.

Now, if the average wind were taken, the aeroplane would tend to be late on 50 per cent. of occasions, a percentage which could be reduced by about five per cent. by "opening up." That means late on 45 per cent. of occasions. Similarly, on the average wind, the aeroplane would tend to be early on the other 50 per cent. of occasions, a percentage which could be reduced by about 10 per cent. by "throttling back"—an aeroplane's performance being more flexible economically "throttling back" than it is "opening up." A further five per cent. or so of early arrivals could be eliminated by dawdling, and another five per cent., approximately, by the delays resulting from instrument approaches and by stacking up. Therefore, in the 50 per cent. wind condition,

the aeroplane would tend to be early on some, uncontrollable, 30 per cent. of occasions.

The percentages I have quoted are, of course, dependent on the slope of the "wind variation probability" curve—the figure of a five per cent. elimination of early arrivals by dawdling might be typical for North Atlantic operations, whereas a figure of 25 per cent. might be more representative for the easier conditions of, say, the South African route. But a significant fact is that high up (above 25,000 feet) nearly all winds are either due West or due East, mostly due West except, so far as is known at present, over India where they are Easterly. This fact will influence future time tables for jet aircraft.

A further practical point in this theoretical analysis is that, whereas the North Atlantic route winds are the most critical of any route in the World up to a height of rather more than 20,000 feet, above that height all routes are pretty well as bad as each other—again a fact which will influence jet services.

Taken on the whole it is true to say that the "50 per cent. time table wind" would result in:—

Arrivals on time 25 per cent. of occasions
Late arrivals ... 45 per cent. of occasions
Early arrivals ... 30 per cent. of occasions

A time table based on the average wind, therefore, would result in more arrivals being late than early; an undesirable state of affairs.

If we increase the "time table wind" to 65 per cent.—that is, base the time table on the headwind component which is not exceeded on 65 per cent. of occasions—the aeroplane will tend to:—

(*a*) Arrive late on 35 per cent. of occasions; reduced to about 30 per cent. by "opening up."
(*b*) Arrive early on 65 per cent. of occasions; reduced to 45 per cent. by "throttling back," by dawdling, by instrument approaches, and by stacking up.

Therefore, on a "65 per cent. time table wind," the result would be:—

Arrivals on time 25 per cent. of occasions
Late arrivals ... 30 per cent. of occasions
Early arrivals ... 45 per cent. of occasions

A further point arises. An arrival tolerance of about five per cent. of the block time might be considered a permissible extension of punctuality. An inspection of average winds and wind "scatter" suggests that such a tolerance would reduce the number of early and late arrivals by approximately a further 10 per cent. each. Given this tolerance, the results from the 65 per cent. wind would be:

Arrivals on time—45 per cent. of occasions (including five per cent. tolerance)
Late arrivals—20 per cent. of occasions
Early arrivals—35 per cent. of occasions.

This still means that relatively "on time" arrivals are less than 50 per cent. of the total. On short routes, flown at reasonably high speeds, the degree of unpunctuality will be slight. On long non-stop services, flown at moderate speeds, the degree of unpunctuality will be greater. Even so, this is about the best which can be achieved economically. It is one of the strongest arguments for a fast aeroplane on a long route.

A statement of general principles such as are set out here, must deal with the general rather than with the particular. However, it apears that, for average stages of up to 500 miles, a 250 m.p.h. aeroplane will be able to achieve punctualities of within 30 minutes on about 75 per cent. of occasions in such winds as prevail normally, whereas on stages of up to 2,000 miles a 1,000 m.p.h. aeroplane would be required to put up a similar performance—a difficult requirement for the fulfilment of which we shall have to wait some time.

In other words, for long and difficult stages there must remain a gap between the day-to-day journey times achieved and the scheduled times advertised.

Therefore, I return to the point that there are, in fact, two forms of journey schedule in relation to any regular airline service. The first is the "average block time achieved," the second is the published time table schedule.

The average block time achieved through the year is the operating schedule made good against the average wind component which prevailed on all the journeys in both directions. The time table schedule is the advertised journey time set down for the convenience of the customers and to attract payload. In this latter connection, an important factor in the selling of space is the insurance that departure times and arrival times are at those hours of the day most convenient and least inconvenient (not the same thing) to the traffic. Nobody likes arriving at London Airport at 3.0 a.m. for instance, although it does happen.

How the scheduled journey time and the achieved journey time can differ on a year's average of operations can be seen by an

analysis of the results gained by three prominent airlines:—

| | AIRLINE "X" | AIRLINE "Y" | AIRLINE "Z" |
|---|---|---|---|
| Average of scheduled journey times | 4.7 hours | 2.57 hours | 1.42 hours |
| Average of achieved journey times | 4.0 hours | 2.50 hours | 1.52 hours |
| Difference in achieved and advertised journey times | 0.7 hrs. less | 0.07 hrs. less | 0.10 hrs. more |
| Per cent. of scheduled journey time | 14.9% less | 2.8% less | 7.1% more |

These examples illustrate the fact that time tables are not being based in practice on any universally accepted ratio between advertised and achieved schedules. Whereas "Airline X" achieved an average journey time markedly less than that advertised, thereby presenting an appearance of early arrivals, "Airline Z" advertised a faster schedule than it could in fact average, and thereby showed a less attractive punctuality record—although, possibly, a more attractive time table. "Airline Y," however, achieved a ratio which, averaging a small percentage of "early" arrivals, might approach the ideal.

All this goes to show that punctuality is the most elusive of the three main operating standards. Although punctuality is

*the politeness of kings, the duty of gentlemen, and the necessity of men of business,*

it is a major difficulty for airlines. While the winds, the vagaries of air traffic control, the human element, particularly in the form of engine maladjustment, and the low standard of mechanical reliability which, unfortunately, exists, still continue to exert a major influence on airline operation, absolute punctuality must remain an unattained ideal, juggle with time tables how you may.* Nevertheless, the faster the aeroplane, the nearer we shall get to time table punctuality. Were the jet-propelled transport attractive for no other reason, the punctuality factor would commend it to the World's airlines.

### 4.3.7. Matching the Aircraft and the Route.

The conception which has been discussed in the foregoing sections sets out in some detail the way in which a desirable standard of reliability, regularity and punctuality can be determined. But it does not touch on the economics which are the heart of the matter and closely linked with the standards sought.

The controlling factor in the economics is the matching of the aeroplane with the route. Either an existing aeroplane has to be fitted to stages selected from those available along a particular route or, for a given stage which has to be operated, a suitable aeroplane must be designed for the job.

To complete here the philosophy of the operating standards, the relationship between the factors influencing regularity and those influencing economics must be defined.

The axiomatic fact is that the capacity payload and the booking payload should be closely related if the aeroplane is to perform economically and that, at an economic load factor, the sold payload (which is the booking payload multiplied by the load factor) and the desirable regularity should be associated.

If the booking payload is substantially less than the capacity payload, then the fuselage is obviously too large for the route and therefore the aeroplane is operating beyond its economic limits—in other words it is not matched to the stage.

If the annual average sold payload is substantially less then the payload which could be carried for the desirable annual regularity *either* the load factor is too low for economy *or* the booking payload, to which the sold payload is related, is too small because the fuselage must be too small. In other words the aeroplane is again not matched to the route.

Therefore to sum up, the desirable booking payload should approximate to the capacity payload. For the desired regularity the capacity payload should not be less than the sold payload divided by the desirable load factor.

These points can be elaborated in relation to two different aircraft in particular conditions as shown in Fig. 9A.

* An example of how far airlines are at present from achieving even a reasonable standard of punctuality is shown by the following extract from *Survival In the Air Age—A Report by the President's Air Policy Commission* (1948)[48] (page 107):—

"An illustration of unpunctuality in good weather is afforded by the figures from an airline flying in and out of New York City in June 1947, which was a good-weather month. This airline offers over-all service considered to be among the best in the country, yet of planes arriving in New York, 89 per cent were late and 46 per cent. of all airplanes were delayed more than one hour. Forty-one per cent. of all airplane departures from New York were late, and 16 per cent. were over one hour late. The steady traveller, most often a business man with appointments to maintain, has learned from bitter experience that his plane will arrive on time about once in ten trips and will depart on time even less often."

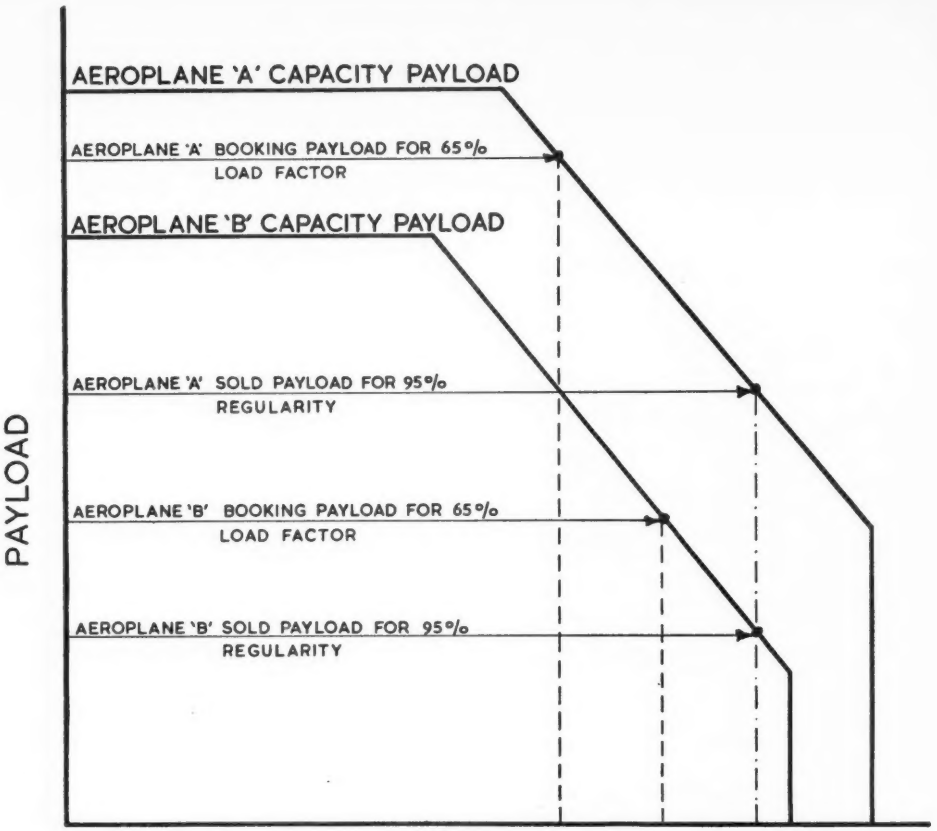
AEROPLANE 'A' CAPACITY PAYLOAD
AEROPLANE 'A' BOOKING PAYLOAD FOR 65% LOAD FACTOR
AEROPLANE 'B' CAPACITY PAYLOAD
AEROPLANE 'A' SOLD PAYLOAD FOR 95% REGULARITY
AEROPLANE 'B' BOOKING PAYLOAD FOR 65% LOAD FACTOR
AEROPLANE 'B' SOLD PAYLOAD FOR 95% REGULARITY
PAYLOAD
Range

Fig. 9A.
Payload/Range chart with regularity factor.
Aeroplane A—(Adequate for route) Aeroplane B—(Marginal for route)

If one aeroplane "A" has a payload at any given range superior to that of a "marginal" aeroplane "B," and combines this advantage with at least equal range with full tanks, then it will have a magnified advantage over aeroplane "B" in both regularity and economy. The reason is that the fuel which can be added to make up the gap between the booking payload and the sold payload is, in proportion, more than the added fuel which can be taken by the inferior aeroplane. In consequence the booking payload for the superior aeroplane "A" can be founded on a shorter range for a given regularity and load factor—alternatively, for the same range a higher regularity can be achieved by aeroplane "A" than is possible with aeroplane "B." There is thus an added bonus in operational performance for a good, compared with a marginal, aircraft on a particular route.

For a generalised analysis of the characteristics of a particular aeroplane a perfectly reasonable assumption is that the fuel required for diversion to an alternative airport should be a constant, related to an arbitrary still-air range. In a more specific examination of an aeroplane on a particular route the alternate distance will, of course, be related to the local geographical and meteorological conditions at the terminal. The distance which separates the desirable alternate—or, in practice, the farther of two selected alternates—from the intended point of arrival will, naturally, influence the amount of fuel carried and hence the payload.

Figure 9B brings out this point. It shows what happens when an aeroplane is stretched beyond its economic limit and how economy and regularity can be related only in terms of stage length and alternate distance for a particular aeroplane.

If, for instance, on a route assumed for the purposes of illustration, a certain aeroplane

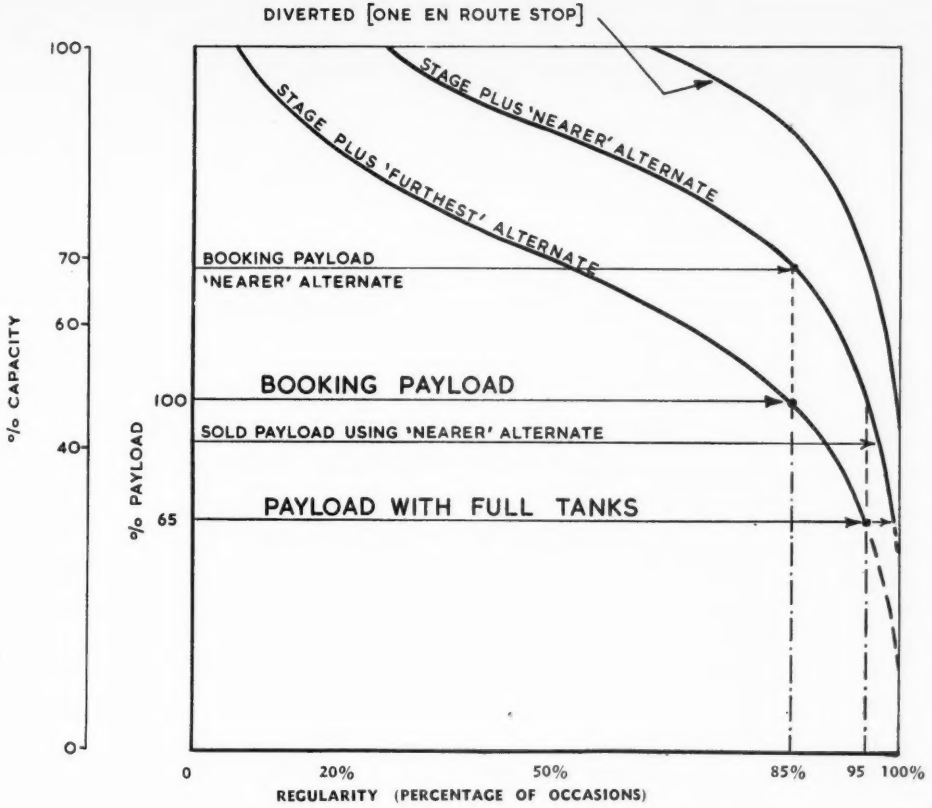


Fig. 9B.
Payload versus Regularity for various ranges over a given stage length.

can carry only 50 per cent. of its capacity payload at the requisite minimum regularity for the stage-plus-the-farthest-desirable-alternate, then the sold payload might coincide with the payload with full tanks—an undesirable state of affairs because the aeroplane would possess no flexibility for increases in regularity as a result of variations in payload below the average.

More important, the fact that the booking payload for the necessary regularity is so far below the capacity payload means that the aeroplane must be running uneconomically.

An improvement can be gained if a nearer alternate could be accepted—a fact which will be governed by weather and traffic. Using a nearer alternate and being able, in consequence, to carry less reserve fuel, the booking payload could be stepped up, more flexibility gained and the economy improved. Even so, Fig. 9B illustrates that the booking payload would be short of the capacity payload. The aeroplane is therefore not ideally matched to the route.

A possible solution would be an intermediate landing to refuel. The booking payload could then approach capacity at the desired regularity. As a result, when the load factor is applied the sold payload would not be uneconomically low and there would be sufficient range flexibility in the aeroplane to improve regularity still further on occasions when the payload fell below the average.

The moral of this is that an aeroplane is matched to a route and stage only so long as:

(*a*) The booking payload, at the assumed minimum acceptable worst season regularity for the stage, closely approximates to the capacity payload, and

(*b*) The planned sold payload, which is the booking payload to which the planned load factor has been applied, is greater than the maximum payload with full tanks and can be carried at the planned regularity throughout the year.

Obviously non-traffic stops should be avoided if possible because they increase

overheads without providing extra revenue. For that reason for any route the most suitable aeroplane will be that which can achieve non-stop operations between traffic centres at the desired regularity and frequency while operating from the commercial basis of a booking payload approximating to capacity.

That, at some length, is the philosophy on which a predetermined standard of reliability, regularity and punctuality can be achieved in commercial operations with a fixed booking payload. It is a philosophy which distils some degree of precision out of a maze of variables.

Although precise figures from past experience are difficult to obtain, a rough analysis of starting delays—which account for both irregularity and unpunctuality—shows that throughout the year mechanical faults still bulk as the largest item, followed by delays caused directly or indirectly by weather. A typical breakdown under present conditions is approximately:—

Delays caused by mechanical faults and faults in equipment ... 44 per cent.
Delays caused by weather and delayed connections ... ... ... 29 per cent.
Delays not directly attributable to weather or mechanical troubles (air traffic control, runway congestion, the human factor, etc.) ... ... ... 27 per cent.

In the worst three months of the year, the total delays were approximately three times those in the best three months, and those attributable to weather, missed connections, and traffic control amounted to some 75 per cent.; the total weather delays in the worst season were four times those of the best three months. Mechanical delays remained approximately constant throughout the year, amounting to only half the weather delays in the worst season, but averaging 50 per cent. more than direct weather delays over the whole year.

This example, which is at best no more than an indication of present trends, serves to illustrate how much remains to be done to improve regularity and punctuality, particularly in improving mechanical reliability, bad weather aids and air traffic control.

Apropos of the relative number of snags in engines as compared with airframes, resulting in traffic delays, one might recall the remark by one very senior maintenance superintendent about a widely used and respected aeroplane that "if the damned crate had no engines, we'd be able to give 100 per cent. perfect mechanical reliability." Which is somewhat of an exaggeration.

Regardless of the practical results obtained in the present state of operating technique, the basic philsophy remains.

To recapitulate. Reliability of arrival must be 100 per cent. for every start made. A regularity of starting of some 95 per cent. can be achieved with 100 per cent. reliability, provided that the aeroplane has adequate tankage to operate the specific route, and provided that mechanical troubles can be mastered and "acts of God" discounted. An absolute punctuality of arrival approaching 50 per cent. is attainable by careful time table planning, once the aimed at degree of regularity has been achieved. On about 85 per cent. of occasions, aeroplanes on a carefully scheduled airline could be either on time, early or insignificantly late—the precise figure varying with the route and the type of aircraft used.

### 4.3.8. Summary of the Philosophy of Operating Standards.

At this point we can pause for a moment to review what has been established.

First of all, to achieve 100 per cent. reliability, the aeroplane must have characteristics adequate for the route which it is to operate. It must have sufficient range and speed at a height suitable to clear *en route* terrain, and to avoid difficult operating regions, such as icing levels. In addition, the aeroplane must be capable of maintaining sufficient of these qualities to arrive safely should one engine fail *en route*.

Secondly, so that an adequate regularity of departure can be maintained, even in the worst season, the fuel tankage of the aeroplane must be sufficient to cover all allowances and reserves, and to make possible operations against the strongest wind component which may be met on up to, say, 95 per cent. of occasions in the worst season. This requirement may be relaxed if an intermediate staging point is available, and if that staging point can be used as a non-scheduled stop, when necessary, without impairing the competitive commercial attraction of the service.

Thirdly, a suitable time table schedule must be chosen for the particular aeroplane operating over the selected route. The scheduled times must be such that a reasonable degree of punctuality can be maintained in relation to the wind fluctuations on the route. Because these foundations may vary

widely with season, the time table may be varied also with season. In practice, for difficult long-stage routes, a reasonable "time table wind" on which schedules can be based has been found to be the strongest wind component met on up to 65 per cent. of occasions.

Having established these standards, which fix the fuel loads and the scheduled times, we have seen that the "booking payload" is governed by the amount of fuel needed for the 85 per cent. worst season regularity (on the assumptions made), and by the fuel reserves and allowances necessary for the flight.

The 85 per cent. worst season regularity involves provision for operation with the full payload which can be carried (100 per cent. load factor) against the most adverse wind component met on up to 85 per cent. of occasions in the worst three months of the year. The payload carried on such operations is the "booking payload."

But tankage is, or should be, available for sufficient fuel to meet the strongest wind blowing on up to 95 per cent. of occasions in the worst season. At the same time, the commercial planning of services will, or should, have provided payload capacity sufficient to carry the traffic offering at an average load factor of 65 per cent. In consequence, the payload offering will be, on the average, some 35 per cent. less than the "booking payload," which represents 100 per cent. load factor at 85 per cent, regularity in the worst season.

The result of this combination of regularity and load factor is that extra fuel can be put in the tanks up to the amount by which the actual payload falls short of the "booking payload"—thereby increasing the annual regularity to perhaps 97 per cent.

In practice, the "booking payload" can be varied from season to season, depending on fluctuations of frequency and traffic. A higher regularity in the worst season can then sometimes be achieved, because of seasonal contractions in the amount of payload offering.

The fuel allowances and reserves have to be established separately for every aeroplane and for every route. For purposes of comparison and of general analysis, they can be taken as fixed for any one type of aeroplane.

The "pre-flight fuel allowances" are not included in the take-off weight and therefore do not influence the payload, although they must be provided for in the total tankage. They comprise the weight of fuel burned from "chocks away" to unstick.*

The "flight fuel allowances" have to be taken into account when estimating both the total tankage required and the booking payload. These allowances comprise the weight of fuel needed for a complete normal operation from unstick to the final switching off of the engine on arrival, less the fuel used cruising at the operating height.

The "fuel reserves" influence both the total tankage which is required and the booking payload. They are made up of the weight of fuel carried for diversion to an alternate, and for the contingency of standing off above the terminal or the alternate—which ever comes last.

The booking payload is then the total payload available after fuel has been taken on board for the "pre-flight allowances," for the "flight allowances," for the necessary reserves, and for the completion of the flight cruising at height against the wind component which, in this analysis, has been taken as that not exceeded on 85 per cent. of occasions in the worst season. Ideally the booking payload should be closely related to capacity payload for economy on the stage.

The actual sold payload is the booking payload modified by the application of the achieved load factor.

Associated with the fuel allowances are the time allowances, from which the block-to-block speeds have to be calculated. The time allowances include the time which has to be allowed for completion of all normal components of a flight plan from "chocks away" to "doors open."

The time allowances, added to the duration spent cruising at operating height, comprise the total block-to-block time for a particular service. The planned block speeds are derived directly from the block times and the stage lengths.

The number of aeroplanes needed to operate a particular service all the year round at a required frequency which will be dictated

* I use the word "unstick" here instead of "start of take-off" because the fuel burned between opening up the engines and leaving the ground is the equivalent of the weight of a passenger on the Brabazon I—an appreciable economic factor. At present the A.R.B. does not permit overloading at the start of the runway to the extent of the fuel burned before the wheels leave the ground. The advent of the turbine in commercial service may perhaps modify this restriction. In this Paper I have made the assumption that it will be.

TABLE X

| "Cancelling Winds" | "Tankage Wind" | "Booking Wind" | "Time table Wind" | "Block-speed Wind" |
|---|---|---|---|---|
| Headwind components *exceeding* those which prevail on 95 per cent. of occasions in the worst season. | Headwind component whose force is *not exceeded* on 95 per cent. of occasions in the worst season. | Headwind component whose force is *not exceeded* on 85 per cent. of occasions in the worst season. | Headwind component whose force is *not exceeded* on 65 per cent. of occasions throughout year. | Average headwind component of those *prevailing* on the days operated. |
| Winds against which operations cannot be undertaken | Worst wind against which operations undertaken | Gives fuel dictating representative annual booking payload. | Compromise "time table wind" | Average "block-speed wind" |
| Cancel operations (unless an intermediate staging point is available) | Determines fuel tankage requirements | Determines booking payload | Suitable for advertised time tables | Gives average block-speed made good |

by the traffic demands, and at a target utilisation, will be set by the block time required for a round trip against the average annual wind component after all delays caused by weather, mechanical faults, control problems and so forth, have been taken into account.

Thus, of all the major factors which govern the desirable operating standards and cannot be influenced by improved engineering, the winds play the predominant part, particularly on long stage operations. A tabulation of the various wind components which determine the different operating conditions can be made as shown above in Table X.

The incidence of these winds should be examined in conjunction with the example of the frequency distribution of winds shown in Fig. 6 (page 612), together with the relationship between regularity and payload shown in Figs. 6A and 6B, which will be found at the end of the paper.

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Such, in general terms, is an expression of the philosophy of operating standards so far as I have been able to determine them in the light of the present state of the art. There may be some controversy on detail, but I believe that, in its broad essentials, the conception is sound.

Just how this theory can be applied to practical examples, I shall endeavour to show in the pages which follow.

## 4.4. THE CONTEMPORARY TYPES—OPERATING STAGE ANALYSIS.

### 4.4.1. "HOUR CHARTS."

Analysis of the operational characteristics of the selected seven contemporary types of aeroplane has been interrupted by this somewhat lengthy digression into the philosophy of operating standards—although such a digression is essential to establish the parameters against which aircraft must be judged.

A difficulty in almost all operational analyses is that the basic parameters are not fixed and can be applied only in one set of circumstances among many variables.

For instance, the quantities required to be found in most operating analyses are, for any given stage length:—

(*a*) Fuel required in prevailing conditions of wind and weather.
(*b*) Allowances and reserves which have to be carried.
(*c*) Payload for stage length.
(*d*) Block speed made good.

Influencing these quantities are:—

The mean weights of the aircraft.
The cruising regime.
The operating heights.
The time and distance covered in climb and descent.

Any attempt to plot these variables against still-air range leads, inevitably, to broad approximations of the percentage of the still-

air range which should be allocated to allowances, reserves, climb and descent. Any attempt to use stage length as the basis leads to exactly the same problem. An exact answer cannot be found, except for individual cases.

In an attempt to overcome this difficulty, I have sought, in what follows, a conception which can be applied to the aircraft in all circumstances, remembering always that an aeroplane in flight is completely immersed in its element and subject to the full drift effect of all the winds that blow.

I emphasise here that the object in view in a broad analysis, such as is attempted in this Paper, is a generalised appreciation of the economic factors in the development of scheduled civil airline operations. Such a generalised approach justifies the making of certain reasonable assumptions which are themselves broad generalisations.

Required answers in the operational analysis, in terms of stage length, block speed or payload must be in a form suitable for being read off quickly against practical parameters for a particular route, after the relevant quantities have been introduced into a performance chart.

Stage length, winds, speeds, weights, allowances, all vary in a manner which cannot be conveniently inter-related. Only one factor can be considered as unaffected. It is time. A 200 m.p.h. "animate" aeroplane would not know whether it had flown 3,000 miles with a 100 m.p.h. tail wind, or no miles against a 200 m.p.h. head wind. All it would know would be that it had flown for 10 hours at its cruising speed. Time is, therefore, the one controllable factor in terms of distance, and "time to be flown" can be taken as a non-variable expression of range.

This is possible because the fuel allowances and reserves can be taken as constants in block time, if a few reasonable assumptions are made, whereas they will vary with the wind when expressed as part of a stage length. Such an approach is satisfactory for a generalised analysis. Generally longer stages require larger fuel reserves while long range aeroplanes operating short stages normally carry fuel for more distant alternates than do short range types—they can afford to do so because there is usually no resulting loss in payload. In taking constant allowances and reserves for individual types of aircraft, the following assumptions provide approximations close to the truth:—

(i) That 75 per cent. of the wind at height is the average wind component effective during the climb and descent.

(ii) That the time taken in climbing to operating height does not vary with changes in the aircraft's take-off weight.*[1]

(iii) That a constant still-air range is allowed for flight to the alternate for each type, irrespective of the length of stage being operated. In practice this diversion allowance will vary with every specific route, according to prevailing weather and location of alternate airports.†[2]

On these assumptions and under this generalised conception the "time to be flown" (or "block hours") does not influence either the fuel allowances or reserves. Only the cruising fuel is affected. The block hours will determine the weight of the aeroplane after a certain amount of fuel has been used, and hence, the average cruising speed and fuel used for a given distance. They in turn will fix the payload.

I have used these facts to construct a chart of aircraft operating performance based on time, into which any value of stage length and wind speed can be introduced to give the various results required.

These "hour charts" form the basis of the analysis of operating performance which I have computed for the seven selected contemporary types of aircraft.

One thing should be made quite clear. Any analysis of operating performance must be related to a specific cruising régime. For instance, there is what is termed "long range cruise" procedure, in which the power is constantly reduced, as fuel is used and the weight of the aeroplane falls. Then there is "constant I.A.S." procedure in which the indicated air speed is kept at a constant figure by variation of power throughout a flight. A third method is the "constant power" procedure. And there are combinations of all

*[1] This introduces a small error with piston-engined types, although it is not as serious as at first appears, because there is considerable flexibility in the relatively slow cruise-climb performance assumed. With turbine-powered types, the error is smaller still, as the lighter the aircraft, the greater the operating height. The more rapid climb will then be largely balanced by the greater height to be reached.

†[2] Still-air distances to alternate airports are assumed to be as follows for the seven types of aircraft considered:—

| | | | |
|---|---|---|---|
| Rapide | 100 miles | Constellation | 500 miles |
| Dove | 170 miles | Orion I | 500 miles |
| Dakota | 300 miles | Brabazon I | 500 miles |
| Ambassador | 420 miles | | |

three, while alterations in cruising height are also common practice as fuel is used.

Each of these cruise procedures will give a different result in terms of payload/range performance for a given amount of fuel. Each method is best for particular conditions and purposes.

For the six piston-engined types, I have chosen a "constant power" cruising procedure as the basis for the analyses. Under this cruising régime, the true air speed will vary throughout a flight as fuel is used and the weight is reduced. This variation in speed and weight can be calculated without difficulty and plotted on a curve. But this procedure—established after climb to a selected cruising height, which is held constant—will not give the longest duration, or, necessarily, the longest range, except in particular wind conditions. It does, however, give a reasonably fast cruising speed which is typical of airline practice. It affords a useful basis for comparison and for illustrating the general possibilities of different classes of aircraft. For the turbine-powered types, as fuel is burned a progressively increased cruising height has been assumed. Engine speeds are maintained constant and the air speed will vary therefore, although the cruising power of the turbine will fall with height.

I make these comments conscious that the procedure I have adopted could be criticised in that, in particular circumstances, the best in range or in payload will not have been extracted from a particular aircraft, especially when flying with that rarity—a tail wind. But, for the purpose of a generalised analysis the assumption of a constant power régime is, I think, the best compromise for piston types, as is constant r.p.m. for turbine types.

With these provisos I have plotted the following points against "hours to be flown" ("block hours"):—

(*a*) True air speed at the varying weights at operating height.
(*b*) Block speed made good for various wind conditions.
(*c*) Fuel allowances and reserves.
(*d*) Fuel carried.
(*e*) Fuel used.
(*f*) Take-off weight.
(*g*) Landing weight.
(*h*) Payload.
(*i*) Take-off and landing distances over a 50 foot screen.

All these quantities can be read off the one set of curves directly.

The results of this approach are to give related quantities for each parameter in terms of hours to be flown ("block hours") in varying wind conditions. Across them a transverse grid has been plotted to give stage miles covered for any particular wind condition for any duration of flight. This method of arriving at stage distance—by taking a block time and by relating that time to the distance which would be covered at the block speed in the wind conditions—permits the effect of the wind to be conveniently incorporated in the allowances for climb and descent—always a difficulty in generalised methods of analysis. The block speed, payload, fuel load and take-off and landing weights can then be read off for the stage length and wind condition required.

The "hour charts" possess the advantage of incorporating on one sheet most of the relevant information required for an initial route analysis.

Because these "hour charts" are somewhat different in approach from previous methods of presenting similar data, a statement of the methods by which stage length data can be calculated may be of interest. I have accordingly included a brief statement of the working method as a footnote to this page.*

* To construct the stage length grid:—

FIRST, select a block time on the base line, say 10 hours.

This block time is made up of two components:

(*a*) Cruising time at operating height, say 9 hours.
(*b*) Time allowances (the time from "chocks away" to "doors open" minus the cruising time at height), say 1 hour.

SECOND, estimate the stage distance covered in the block time in the prevailing wind conditions, *i.e.*, in 10 hours.

This stage distance is made up of two parts:—

(*a*) Cruising distance at operating height which is the cruising time × the average true ground speed at operating height under the wind conditions, *i.e.*, 9 hours × say 200 m.p.h. = 1,800 miles.

(*b*) Air mileage covered on climb and descent (which is assumed constant), say, 45 plus 55 miles = 100 air miles covered in, say, 0.65 hours.

Apply wind effect to climb and descent air mileage using 75 per cent. of wind component at operating height. This gives the geographical distance covered on the climb and descent under the particular wind conditions. Result say 90 miles.

Stage distance covered in block time is then cruising distance at operating height, plus distance covered on climb and descent = 1,800 + 90 miles = 1,890 miles.

In the example quoted the stage length for the assessed conditions works out at 1,890 miles, and the average block speed 189 m.p.h. at an average true ground speed of 200 m.p.h.

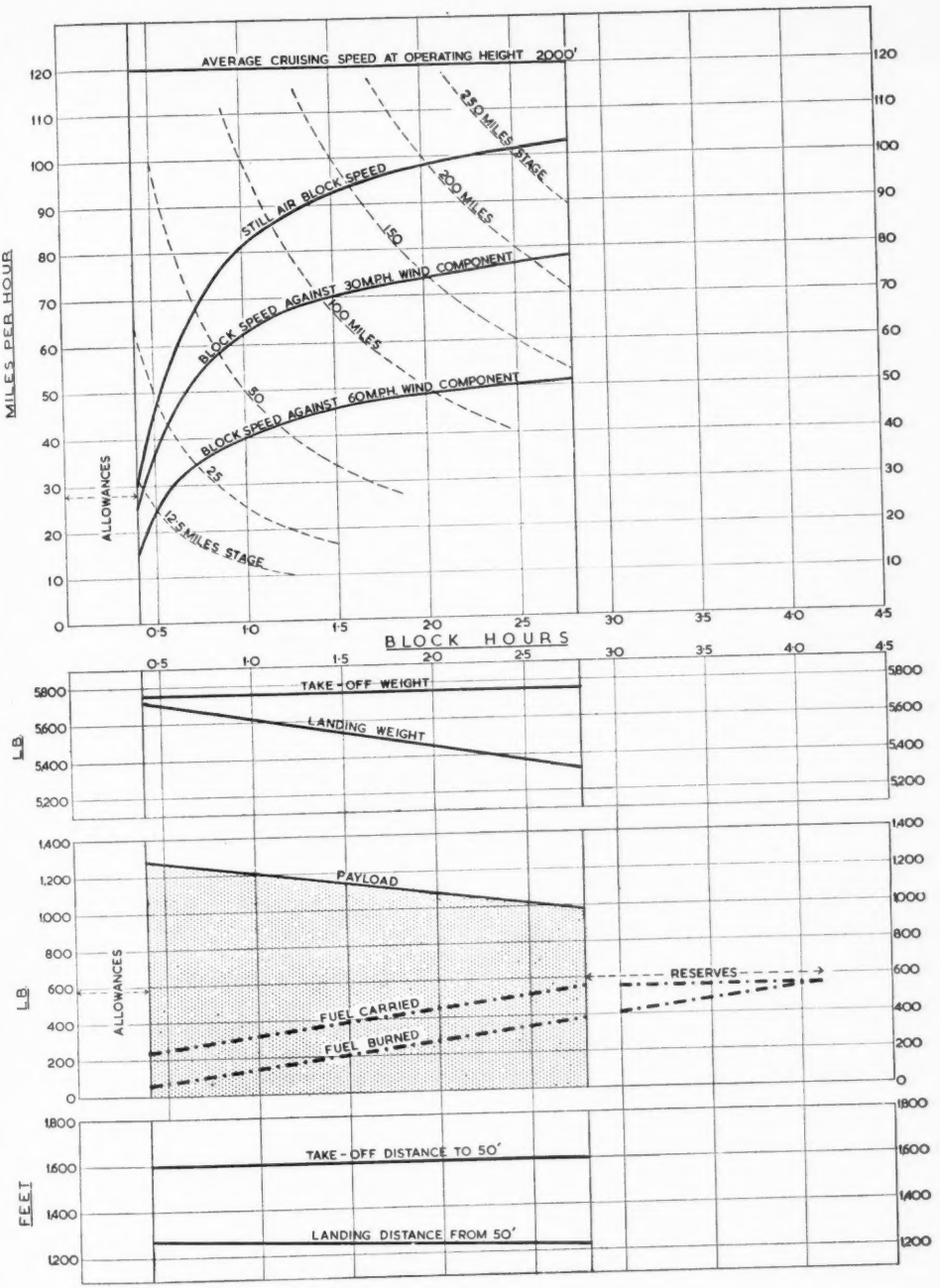



Fig. 10.

De Havilland Rapide III D.H.89A

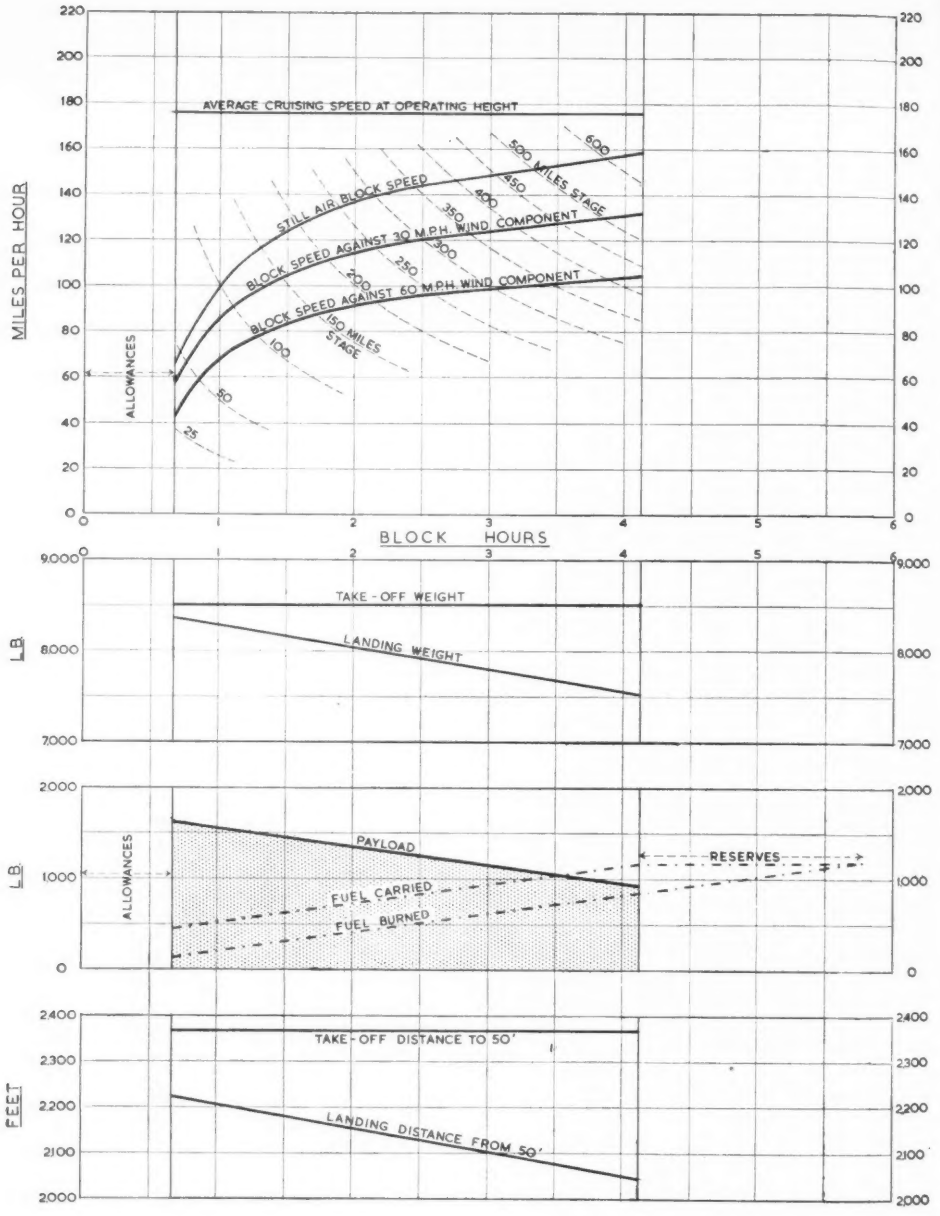



Fig. 11.
De Havilland Dove I D.H.104

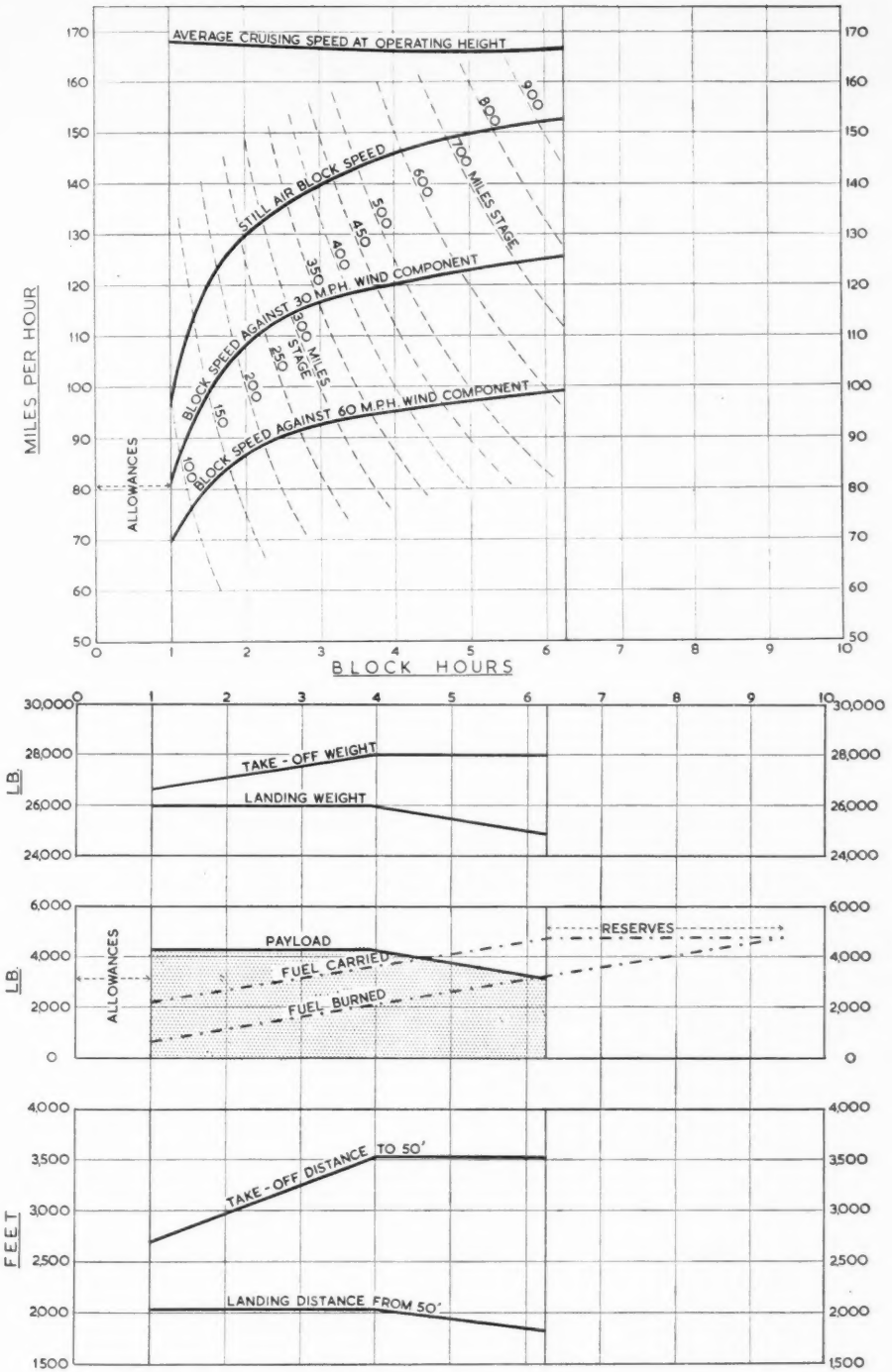



Fig. 12.
Douglas Dakota III C—47A

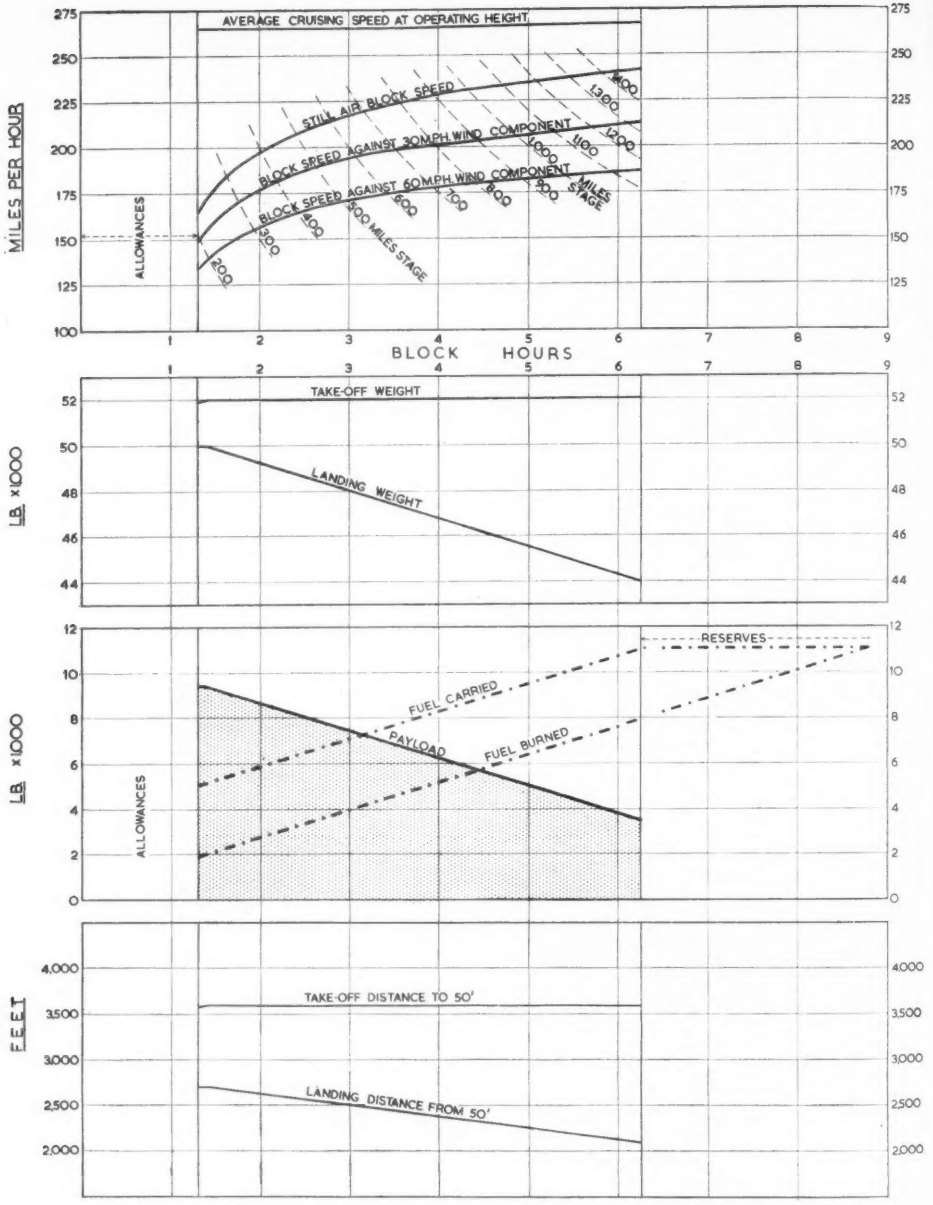



Fig. 13.

Airspeed Ambassador II A.S. 57

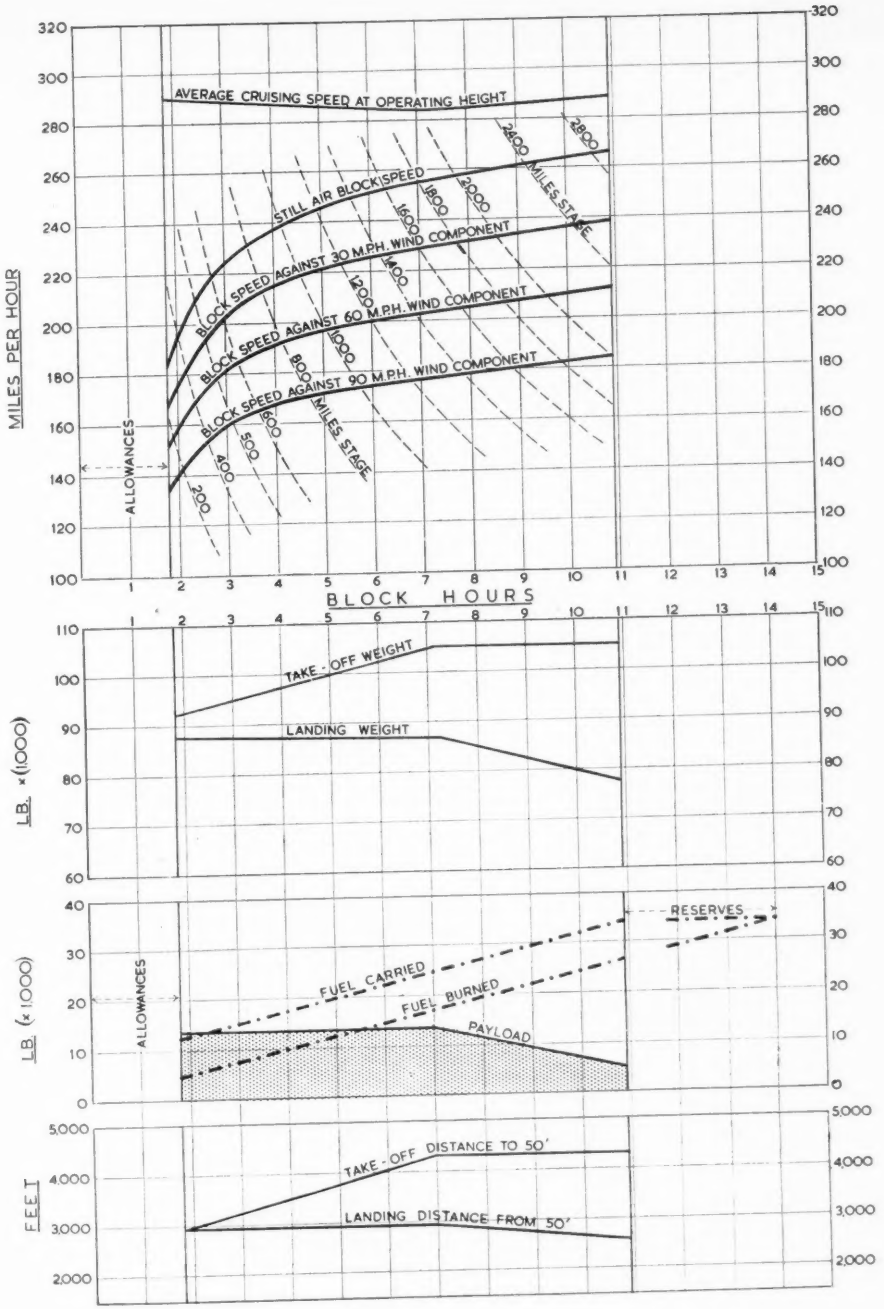



Fig. 14.
Lockheed Constellation IV 749—49—34

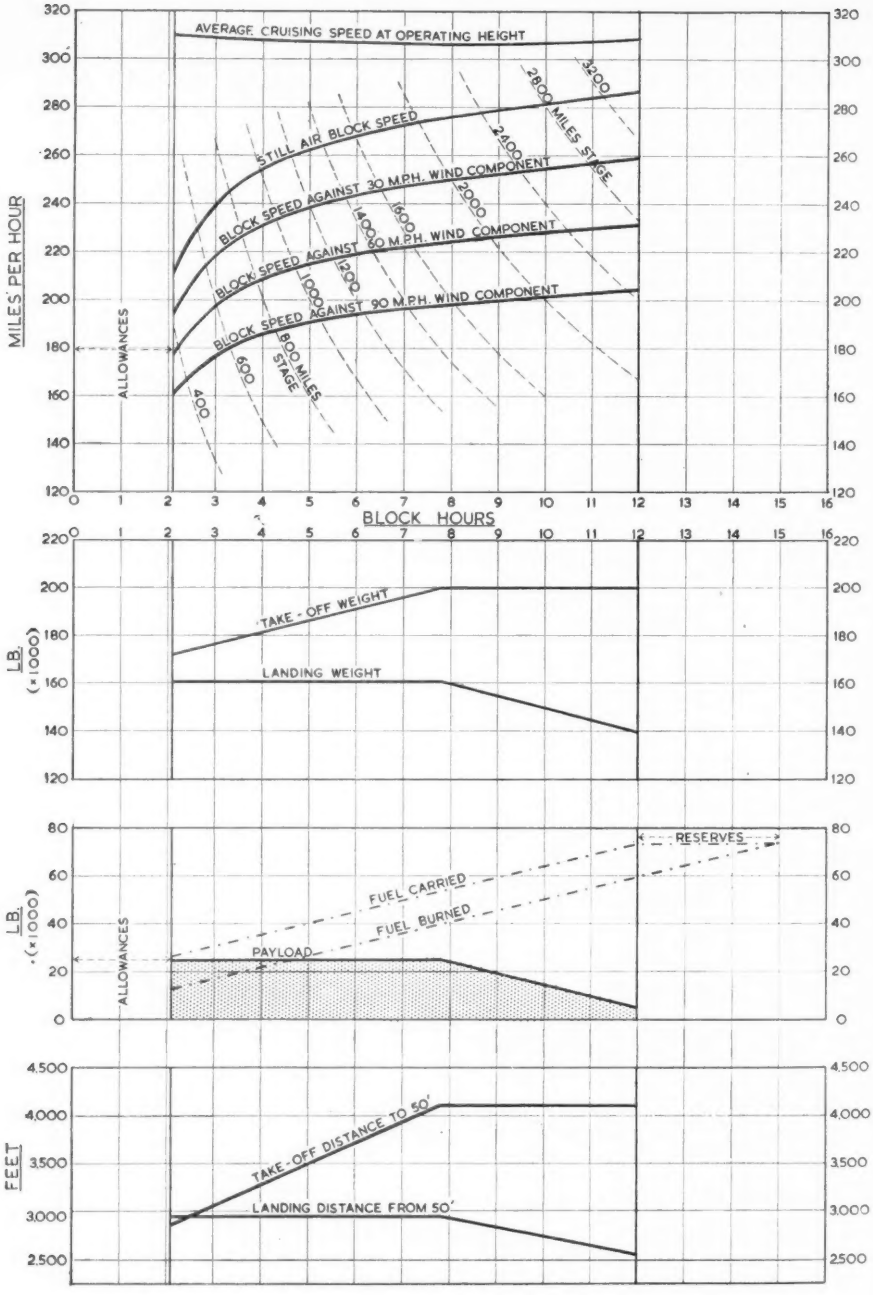



Fig. 15.
Orion I

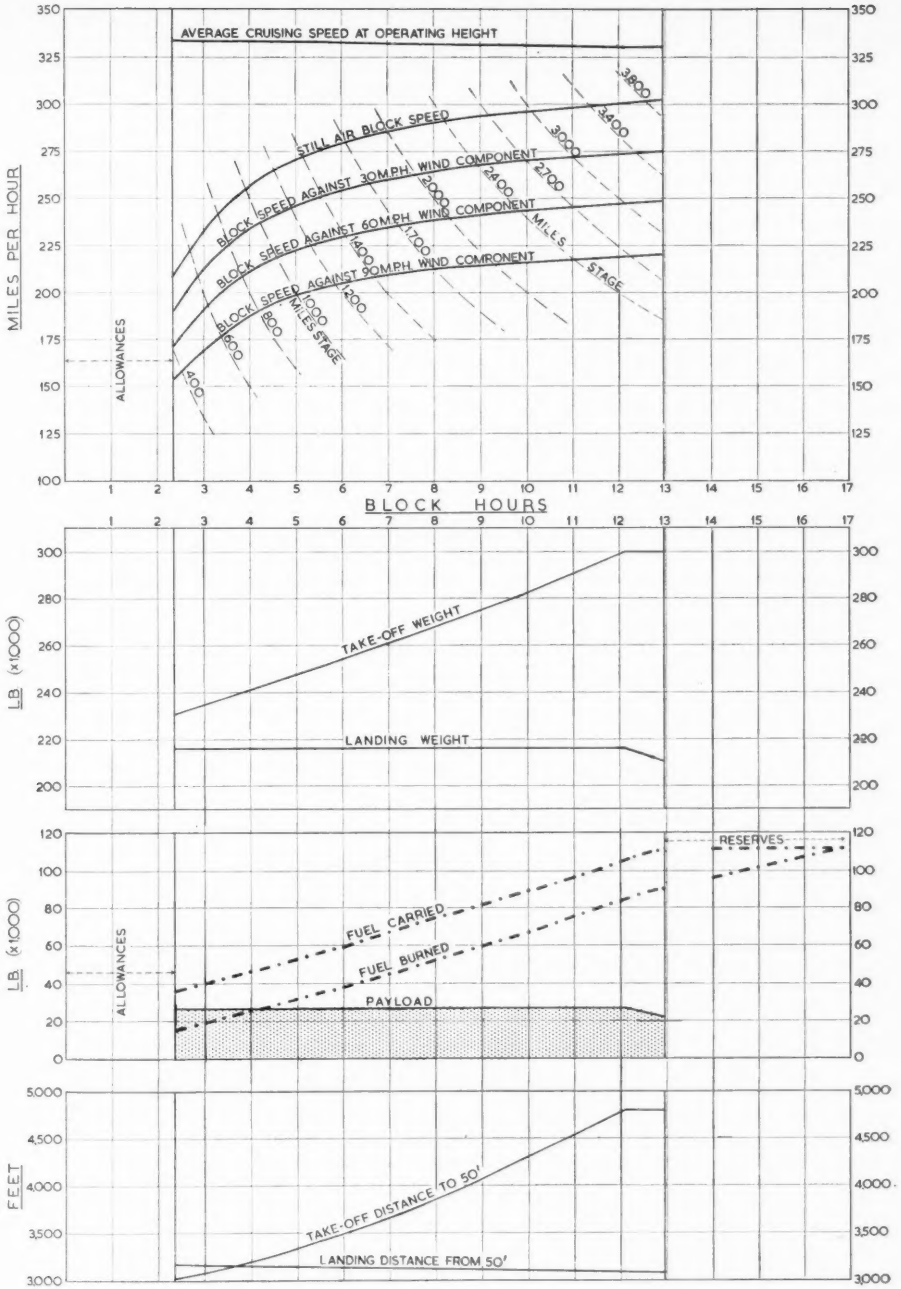



Fig. 16.
Bristol Brabazon IB Type 167
(The operating height varies between 28,000 ft. and 38,000 ft.)

## TABLE XI

## TABULATED SUMMARY OF "HOUR CHARTS"

(For the seven selected contemporary civil aircraft)

| | Rapide III | Dove I | Dakota III | Ambassador II | Constellation IV | Orion I | Brabazon IB |
|---|---|---|---|---|---|---|---|
| 1. Cruising height ... | 2,000 feet | 8,000 feet | 8,000 feet | 20,000 feet | 20,000 feet | 20,000 feet | 33,000 feet |
| 2. Capacity payload ... | 1,350 lb. | 2,100 lb. | 7,870 lb. | 11,140 lb. | 13,740 lb. | 25,000 lb. | 27,200 lb. |
| 3. Total fuel reserves ... (diversion & stand off) | 173 lb. | 333 lb. | 1,535 lb. | 3,150 lb. | 7,430 lb. | 14,020 lb. | 21,010 lb. |
| 4. Flight time on reserves | 1·3 hours | 1·65 hours | 3·2 hours | 3·0 hours | 3·1 hours | 3·1 hours | 3·88 hours |
| 5. Distance covered in climb and descent in still air | 12 miles | 44 miles | 97 miles | 215 miles | 332 miles | 453 miles | 490 miles |
| 6. Shortest stage* block speed, still air | 29 m.p.h. | 66 m.p.h. | 97 m.p.h. | 165 m.p.h. | 184 m.p.h. | 123 m.p.h. | 208 m.p.h. |
| 7. Payload for shortest stage | 1,270 lb. | 1,633 lb. | 4,277 lb. | 9,492 lb. | 13,740 lb. | 25,000 lb. | 27,200 lb. |
| 8. Time on shortest stage (allowances) | 0·4 hours | 0·66 hours | 1·0 hours | 1·3 hours | 1·8 hours | 2·12 hours | 2·36 hours |
| 9. Max. stage distance covered with payload for shortest stage in still air | 12 miles | 44 miles | 570 miles | 230 miles | 1,800 miles | 2,160 miles | 3,645 miles |
| 10. Block speed ... ... | 29 m.p.h. | 66 m.p.h. | 145 m.p.h. | 170 m.p.h. | 255 m.p.h. | 276 m.p.h. | 300 m.p.h. |
| 11. Payload for max. stage length | 980 lb. | 940 lb. | 3,120 lb. | 3,420 lb. | 5,050 lb. | 5,000 lb. | 22,100 lb. |
| 12. Max. stage length no wind | 290 miles | 650 miles | 970 miles | 1,512 miles | 2,900 miles | 3,520 miles | 3,920 miles |
| 13. Block speed ... ... | 103 m.p.h. | 158 m.p.h. | 154 m.p.h. | 242 m.p.h. | 266 m.p.h. | 292 m.p.h. | 303 m.p.h. |
| 14. Max. stage length 30 m.p.h. wind ... | 220 miles | 550 miles | 780 miles | 1,337 miles | 2,600 miles | 3,192 miles | 3,560 miles |
| 15. Block speed ... ... | 78 m.p.h. | 132 m.p.h. | 126 m.p.h. | 123 m.p.h. | 238 m.p.h | 265 m.p.h. | 275 m.p.h. |
| 16. Max. stage length 60 m.p.h. wind | 143 miles | 435 miles | 620 miles | 1,171 miles | 2,330 miles | 2,867 miles | 3,205 miles |
| 17. Block speed ... ... | 51 m.p.h. | 104 m.p.h. | 99 m.p.h. | 189 m.p.h. | 213 m.p.h. | 238 m.p.h. | 248 m.p.h. |
| 18. Max. stage length 90 m.p.h. wind | — | — | — | — | 2,000 miles | 2,538 miles | 2,853 miles |
| 19. Block speed ... ... | — | — | — | — | 183 m.p.h. | 211 m.p.h. | 220 m.p.h. |

* Shortest stage is assumed to be that which would be completed during climb to and descent from normal operating height

"Hour charts" for the seven selected contemporary aircraft are set out in Figs. 10 to 16. I pay tribute here to the work which my colleague, Mr. P. W. Brooks, has put into the compilation of these data.

The "hour charts" show that, for the assumed conditions, at one end of the scale, the Rapide can fly a maximum stage length of 290 statute miles in still-air, carrying 980 lb. of payload at a block-to-block speed of 103 m.p.h., whereas at the other end of the scale, the Brabazon Ib could fly a maximum stage length of 3,920 statute miles in still-air, carrying 22,100 lb. payload at a block-to-block speed of 303 m.p.h.

In more detail, the results can be tabulated as shown in Table XI.

The data summarised there indicate that, whereas the Rapide, the Dove, the Dakota and the Ambassador have fuselages big enough to carry the largest normal payload they can lift for their shortest effective operational stage the other three types are limited in capacity by fuselage size or wing strength. This of course assumes payloads of average density, including full passenger loads. The Dakota is the only aeroplane seriously limited by landing weight restrictions. The need to keep the landing weight to 26,000 lb. (brakes being the limiting factor) restricts the payload of the Dakota for durations of less than four hours.

The flexibility of the Ambassador at its present contemplated weights, particularly when the larger tankage is provided, is shown by its ability to complete a stage length of 1,170 miles against a 60 m.p.h. headwind. That is nearly twice the maximum stage length of the Dakota in similar circumstances, performed at nearly twice the block speed with 10 per cent. more payload. This is, of course, as it should be, considering the respective dates and weights of the two aircraft.

The summary has brought out the fact that the Constellation, the Orion and the Brabazon I are all restricted in payload capacity for short or moderate ranges—by volumetric capacity limitation in the Constellation (hence the "Speedpak") and in the Orion, and by wing bending moment in the Brabazon. The Constellation has a range adequate for the North Atlantic stage between Shannon and Gander, even against a 90 m.p.h. headwind—although with a payload reduced to 5,050 lb. (about 20 passengers). That means that the Constellation can achieve a regularity of not less than 97.4 per cent. on the North Atlantic westbound stopping service via Shannon and Gander when operating with full tanks, although with a relatively small payload. It is, in fact, one of the very few commercial aeroplanes of to-day with range adequate for all-the-year-round Atlantic services on the direct route.

The figures for the Orion I illustrate the sort of improvement in range and payload which could be gained by an equally developed conventional aeroplane of double the weight of the Constellation. The increase is of the order of 80 per cent. in payload and 20 per cent. in range.

The estimated figures for the Brabazon Ib are by far the most impressive. With its capacity payload of 27,200 lb. and fuel reserves amounting to 21,010 lb. (enough for 3.88 hours for diversion to an alternate airport and for stand-off over it),* the Brabazon Ib has an estimated stage length of 3,646 miles in still-air. This means that it could carry its full payload of 100 passengers, plus a ton of mail and freight, non-stop from New York to London with almost 100 per cent. regularity, a performance far in excess of that of any contemporary landplane, although rivalled by the SR-45 flying boat.

Flying in the opposite direction, westbound, against a continuous 90 mile an hour head wind component, the Brabazon Ib would be able to carry 22,100 lb. of payload non-stop from London to Halifax, Nova Scotia, (where there is an adequate airport) and then have reserves adequate for a further 3.88 hours flying—enough to carry it on to New York in good weather. It could complete the non-stop flight from London to New York with this 10-ton payload and all reserves against a continuous head wind component of about 40 miles an hour, giving an annual regularity of at least 60 per cent. non-stop westbound and practically 100 per cent. with one stop.

* A commentary on the handicap imposed on turbine-powered aircraft by the need for diversion and stand-off reserves is provided by the fact that the Brabazon Ib will require more fuel to divert to an alternate airport (covering 500 still-air miles at 3,000 feet on six engines at 200 m.p.h.) than it will to climb to operating height on eight engines and descend on six engines at an average of 260 m.p.h. (210 m.p.h. climb speed, 290 m.p.h. descent speed). The relative figures for fuel are:—
Taxi, climb and descent (2.36 hours), 11,900 lb.; diversion to alternate (2.5 hours), 13,630 lb.

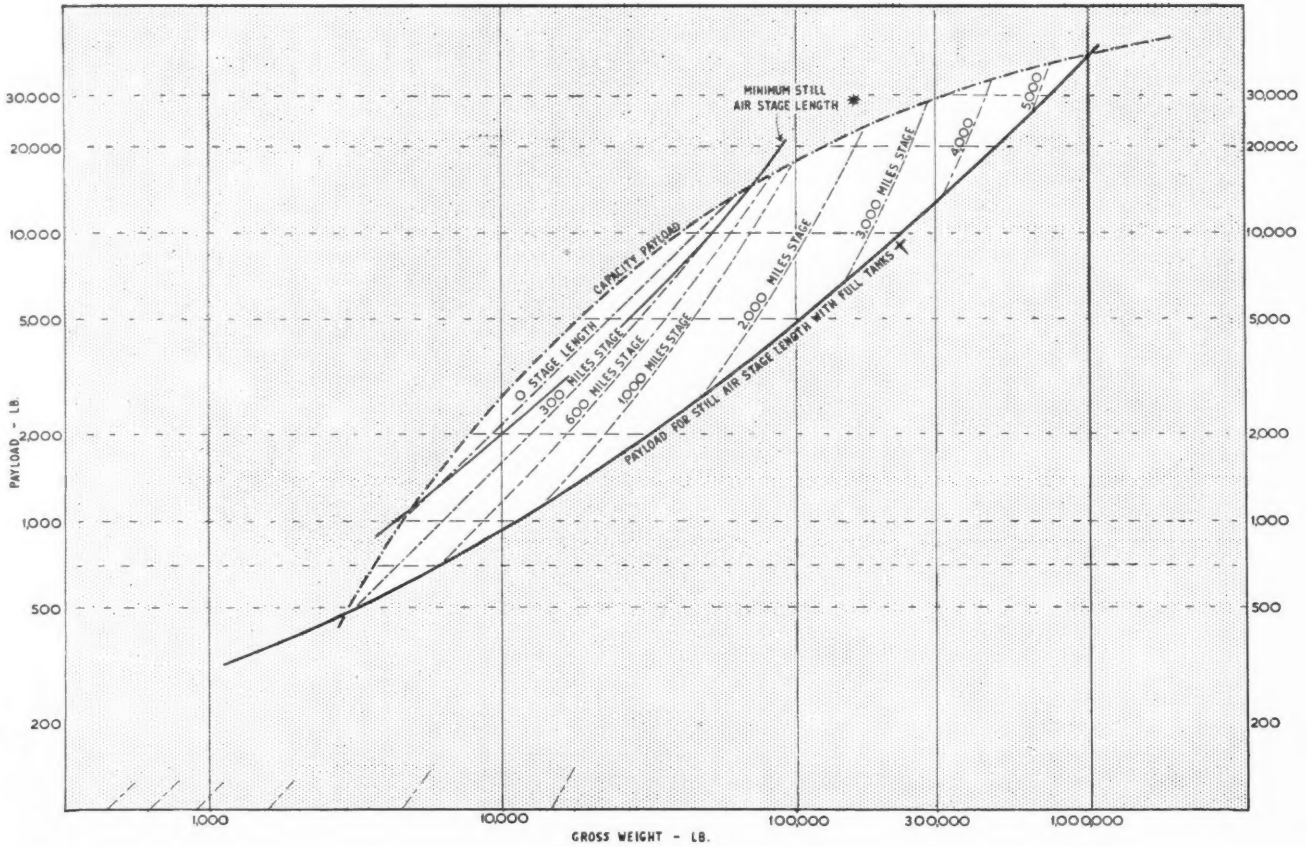



Fig. 17.

Gross Weight v. Payload (for various still-air stage lengths). Typical trends in 1948. (Figure illustrating trend of payload carried by typical contemporary transport aircraft of various gross weights for specific stage lengths in still air. Typical limitations imposed by fuselage capacity and by normal installed tankage are indicated.)

* Stage distance covered in normal climb to operating height and descent.

† An arbitrary figure dictated by economics of minimum Payload worth carrying and representative of present practice.

* Stage distance covered in normal climb to operating height and descent.
† An arbitrary figure dictated by economics of minimum Payload worth carrying and representative of present practice.

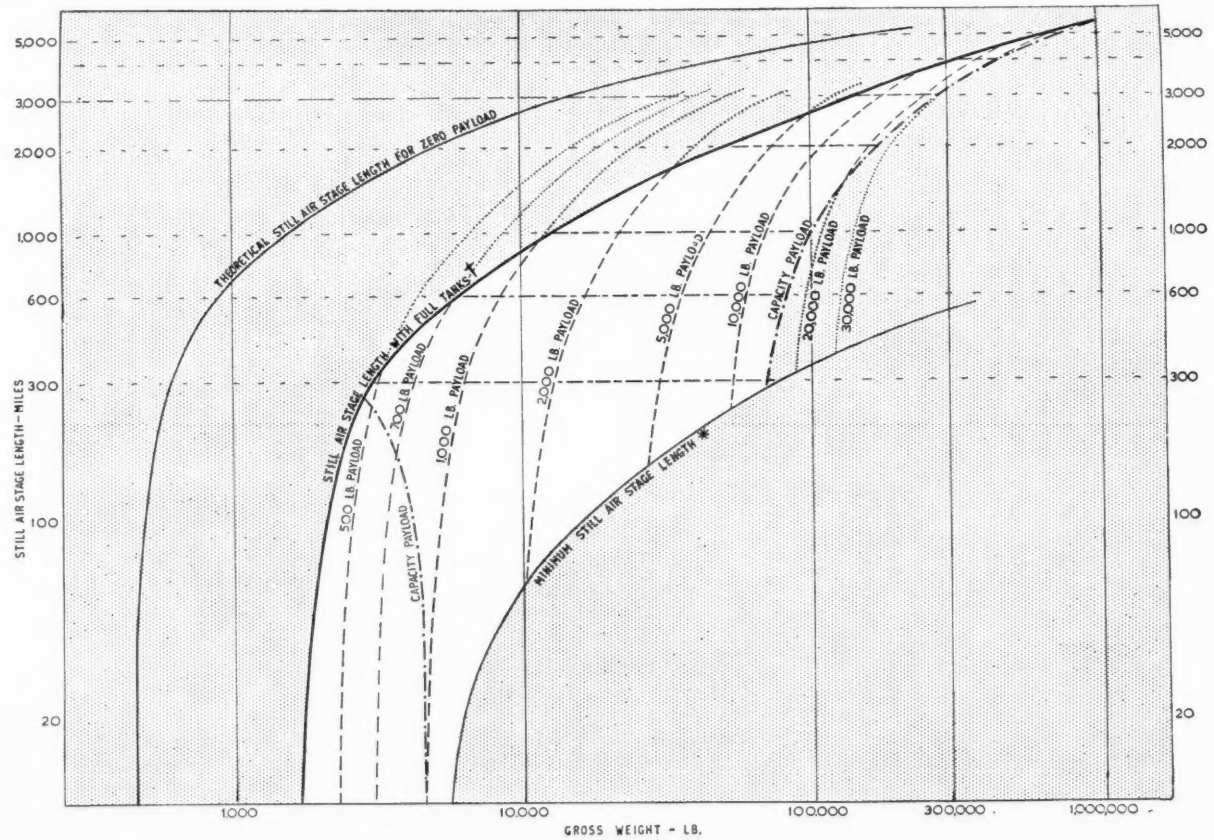



Fig. 18.

Gross Weight v. Still-Air Stage Length (for various payloads). Typical trends in 1948. (Figure illustrating trend of stage length achieved by typical contemporary aircraft of various gross weights carrying specific payloads. Typical limitations imposed by tankage and by fuselage capacity are indicated.)

* Stage distance covered in normal climb to operating height and descent.

† An arbitrary figure dictated by economics of minimum Payload worth carrying and representative of present practice.

All this means that, with the developments in "pressure pattern" navigation mentioned earlier, which are likely to have materialised by the time the Brabazon I is in service, a practical annual non-stop regularity of approaching 85 per cent. should be possible, westbound, throughout the year between London and New York allowing for full reserves. There is at present no other commercial landplane built or building which can approach this.

We should remember, of course, that at least five years must elapse before the Brabazon Ib could be in regular commercial service on the North Atlantic. A design can develop a long way in five years, particularly with propeller-turbine engines still in their early stages. Therefore the results quoted for the Brabazon I should be regarded as an indication of potentialities rather than as a precise statement of performance. We are entitled to hope that the results of five years' work will result in attainments which may exceed present estimates. On the other hand, aeronautics is a notoriously optimistic vocation.

With these things in mind, what these figures amount to on a generalised basis for aeroplanes in the range of sizes from 5,000 to 1,000,000 lb. is illustrated in Figs. 17 and 18. They show the sort of results we have achieved so far in terms of payload, range and aircraft size in the present state of the art and how the trends are shaping.

For instance, from Fig. 17, whereas for a 600 mile stage length in still-air a payload of 6,000 lb. could be carried by a 40,000 lb. aeroplane, an aeroplane of 78,000 lb. would be required to carry the same payload for 2,000 miles. Similarly, from Fig. 18, an aeroplane of 40,000 lb. gross weight could carry a payload of 5,000 lb. for 1,000 still-air stage miles, but for 1,650 miles could lift only some 2,000 lb. of payload. Again, if a payload of 20,000 lb. has to be carried for a still-air stage length of 1,000 miles, Fig. 18 shows that an aeroplane of 116,000 lb. gross weight will be necessary.

The same figures show how capacity payload is related to gross weight in present practice and the maximum and minimum still-air stage lengths on contemporary standards.

These figures make interesting enough studies on their own. But they are only half the story. Allied with performance must go the economics, both the cost per hour and the revenue per mile, the latter depending on the payload. The most successful aeroplane will incorporate a nice blend of high performance with low operating cost and large revenue potential. These qualities should be so balanced and related to contemporary competitive performance that, when put into service by an efficient operator under commercial conditions, they make possible an annual working profit.

## 4.5. OPERATING COSTS.

### 4.5.1. The Three Divisions.

Having established the operating performances for a range of aeroplanes, the meaning of their performances in terms of operating costs and revenue possibilities remains to be determined. Can a flight from "A" to "B" in prevailing wind conditions and with a practical scale of overheads, be performed economically? And if so what are the typical figures for an annual operation?

Past experience is again a valuable guide. Earlier in this paper, I set out certain statistics for six international airlines over recent 12 months' periods (Table II). Returning to those figures, we find that they can be broken down further on the basis set out in Table XII.

An obvious necessity in reducing costs of operations by individual airlines to a comparative basis, is to remove the variable produced by the use of different sizes of aircraft.

Experiment suggests that, by comparing costs for different fleets of aircraft on the basis of "cost per ton of gross weight"—either absolute or per hour or per mile—the influence of varying sizes of aircraft can be more or less eliminated.

The "non-dimensional" result from this reduction affords a useful basis for comparison and has the merit of showing up the poor aeroplane whose payload is low for a given take-off weight and stage length. It reveals also operational inefficiencies.

Inspection of the specific figures in Table XII shows that whereas revenues have varied from 3.93 pence per ton of gross weight per mile (for an airline operating commercially inefficient types of aircraft at a 58.55 per cent. load factor) to 6.55 pence per ton of gross weight per mile (for an airline running at 73.20 per cent. load factor), operating costs range from 9.65 pence per ton of gross weight per mile (for an airline with high overheads

and a multiplicity of types) down to 4.95 pence per ton of gross weight per mile (for an airline with a high utilisation and only two types of modern commercial aircraft). In exceptional circumstances one airline reduced costs still further.

Turning from facts to forecasts, estimates of operating costs have formed the subject of numerous papers and treatises. Various formulæ have been evolved on which to compare different aircraft—the best known of them being the American "A.T.A." formula, founded on the pioneering work undertaken by Mentzer and Nourse in their memorable paper of 1940[12]. The S.B.A.C. has recently, I believe, been endeavouring to establish an equivalent formula on British standards, while the Ministry of Supply has for some time used a modified A.T.A. formula on which to compare direct operating costs.

Certainly these formulæ perform a useful function in setting out a common basis on which different aircraft can be compared in different parts of the World. But I trust that I shall be acquitted of any intention of attempting to undermine established and useful practice, when I say that I believe that these formulæ do not come very close to results likely to be gained in airline service—particularly because they ignore two dominant influences, overheads and stage length.

In my opinion there is only one satisfactory way of assessing likely economic results from particular aircraft operating over particular routes. This is to analyse the operating costs and the revenue potentials over a full year, taking into account the essential parameters of overheads, stage length, achieved block time, utilisation and number of aircraft in a fleet.

We have already seen (page 589) that costs of aircraft operation depend largely on three things:—

How much the aeroplane is used in a year (utilisation).

How long it flies between landings (stage length, cruising speed and wind), and

To what extent it is saddled with overheads (administrative efficiency).

Revenue, on the other hand, depends directly on the amount of payload which can be attracted per mile.

The costs incurred can therefore be divided into:—

(*a*) Those annual costs which arise irrespective of hours flown.

(*b*) Those costs which are dependent directly on hours flown (*e.g.*, fuel and oil), and

(*c*) Those costs associated directly with take-off and landings (*e.g.*, station costs, landing fees, etc.).

Operating costs, I submit, fall more naturally under these three independent heads, rather than under the heads of direct and indirect costs familiarly quoted. The three main heads, therefore, are, I suggest:—

I. FIXED ANNUAL COSTS—independent of hours flown or miles covered.

II. HOURLY CRUISING COSTS—the direct flying costs per hour of utilisation, at the rate of cost incurred when cruising at operating height.

III. TAKE-OFF AND LANDING COSTS—depending on the average stage lengths flown in a defined period. They are the extra costs associated with each landing and take-off cycle over and above the costs associated with cruising at height.

The totals of operating costs summed under these heads depend directly on the overhead expenses, the hours flown and number of landings made in a year.

Individual airlines have their own methods of estimating operating costs—in line with their own particular conditions and experience. I am not seeking here to offer any evidence which will influence specialised analyses of individual aircraft by operating companies on their own routes. But I am attempting, instead, to set down a realistic method of compiling estimates of total costs on a generalised basis which will be readily applicable to any aircraft and easily applied to typical route studies. The analysis therefore goes beyond the field of the normal cost formulæ. The results of such comprehensive estimates of cost, when combined with parallel estimates of revenue, will be comparable rather than quantitative for different types of aircraft but, I trust, will be of the right practical order; requiring modification only for specific operating circumstances peculiar to every airline and every route.

The fundamental conception is that:—

*The costs are governed by the hours flown and the number of landings (i.e., the stage length).*

*The revenue is governed by the miles covered and the load factor achieved.*

And both must be assessed over a full year to take into account seasonal fluctuations of frequency, intensity of operation, traffic delays and the volume of traffic offering. The costs governed by these various influences can be divided into 35 items and tabulated under the three headings shown in Table XIII.

Returning again to the evidence provided by the breakdown of known costs for the six airlines "A" to "F" we find, in Table XII, that the averages work out at £3,780 per ton of gross weight for fixed annual costs, at £1 15s. per ton of gross weight for hourly cruising costs, and at £4 14s. per ton of gross weight for the extra costs per take-off and landing cycle. A further inspection suggests that the average is unbalanced on the high side because of two particularly high cost operators among the six. The cost of airlines "B" and "F" for the years quoted were undoubtedly in some respects higher than need be expected in the future.

From these figures, and from further inspection of the detailed costs of other airlines, fair figures for the respective totals per

TABLE XIII

COSTS DIVISIONS

| FIXED ANNUAL COSTS (Independent of hours flown and miles covered) | HOURLY CRUISING COSTS (Direct flying costs incurred over the full utilisation period at the rate of cost incurred while cruising at operating height) | TAKE-OFF & LANDING COSTS (Additional costs associated with each landing and take-off cycle, from operating height to operating height) |
|---|---|---|
| 1 Amortisation of airframe. | 18 Fuel consumed cruising at height. | 30 Extra-to-cruising fuel used on take-off and climb. |
| 2 Amortisation of engines. | 19 Oil consumed. | 31 Extra - to - cruising maintenance of airframe. |
| 3 Amortisation of propellers. | 20 Maintenance of airframe (cruising). | 32 Extra - to - cruising maintenance of engines. |
| 4 Amortisation of radio. | 21 Maintenance of engines (cruising). | 33 Extra - to - cruising maintenance of propellers. |
| 5 Insurance of aircraft. | 22 Maintenance of propellers. | 34 Extra - to - cruising maintenance of radio. |
| 6 Interest on capital invested in aircraft. | 23 Maintenance of radio. | 35 Landing fees. |
| 7 Engineering base overheads. | 24 Salaries and expenses of cockpit crew. | 36 Passenger ground service. |
| 8 Amortisation of ground equipment. | 25 Salaries and expenses of cabin crew. | 37 Out station operation. |
| 9 Interest and insurance of ground equipment. | 26 Insurance of crew. | 38 *Total Take-off and Landing Costs.* |
| 10 Salaries and pensions of administrative staff. | 27 Insurance of passengers. | |
| 11 Headquarters accommodation. | 28 Air service for passengers and crew. | |
| 12 Administrative office expenses. | 29 *Total Hourly Cruising Costs.* | |
| 13 Accommodation at out stations. | | |
| 14 Technical development and flying training. | | |
| 15 Advertising and publicity. | | |
| 16 Traffic and sales. | | |
| 17 *Total Fixed Costs.* | | |

*N.B.*—Fixed Costs and Hourly Cruising Costs present no fundamental difficulties. The Take-off and Landing Costs are new in conception and therefore may require some explanation. They comprise an important factor in any airline operation. They are extra costs, over and above the hourly costs, which are associated with each cycle of take-off and landing. They include the additional or reduced costs on taxi, take-off, climb, descent, circuit and approach, over and above the flat rate at normal cruise at height, and, more important, the overheads of passenger and ground services, landing fees, and, biggest of all, ground operations at out stations.

Take-off and Landing Costs are therefore a constant per landing for any particular aeroplane flying a specific route and can be superimposed on the normal cruising costs from the moment descent from operating height begins, through the landing and turn round until, after take-off and climb, the aeroplane resumes its cruising regime again at operating height. Take-off and Landing Costs remain a constant per landing in all circumstances associated with a particular aeroplane flying on a specific route. The percentage which the Take-off and Landing Costs bear to the Hourly Costs varies with the number of landings made per hour.

ton of gross weight for piston-engined aircraft in the present state of scheduled airline development appear to be:—

FIXED COSTS: £3,500 per annum.

HOURLY CRUISING COSTS: £1 15s. 0d. per hour flown.

TAKE-OFF AND LANDING COSTS: £4 10s. 0d. per operating cycle of landing and take-off.

These figures can be used as a useful check against results estimated for new aircraft.

Taking these average figures for the annual fixed costs, hourly cruising costs and landing costs of scheduled airlines and combining them for various utilisation and a range of hours flown between landings, a series of generalised cost curves can be established. They are set out in Fig. 19. In fact, the trend of large aircraft is towards slightly lower costs per ton of gross weight than those shown. Small aircraft will similarly tend towards slightly higher costs per ton of gross weight, although the difference is of the order of only about ten per cent. These facts are also indicated in Fig. 19, which is based on a typical aeroplane of about 68,000 lb. (30 tons) gross weight.

An additional factor is the effect of different numbers of aircraft in a fleet. Examination shows that, although costs rise sharply if a fleet comprises less than six aircraft because of the small number of units over which fixed costs have to be spread, the




Fig. 19A.
Theoretical variation of Operating Cost with size.

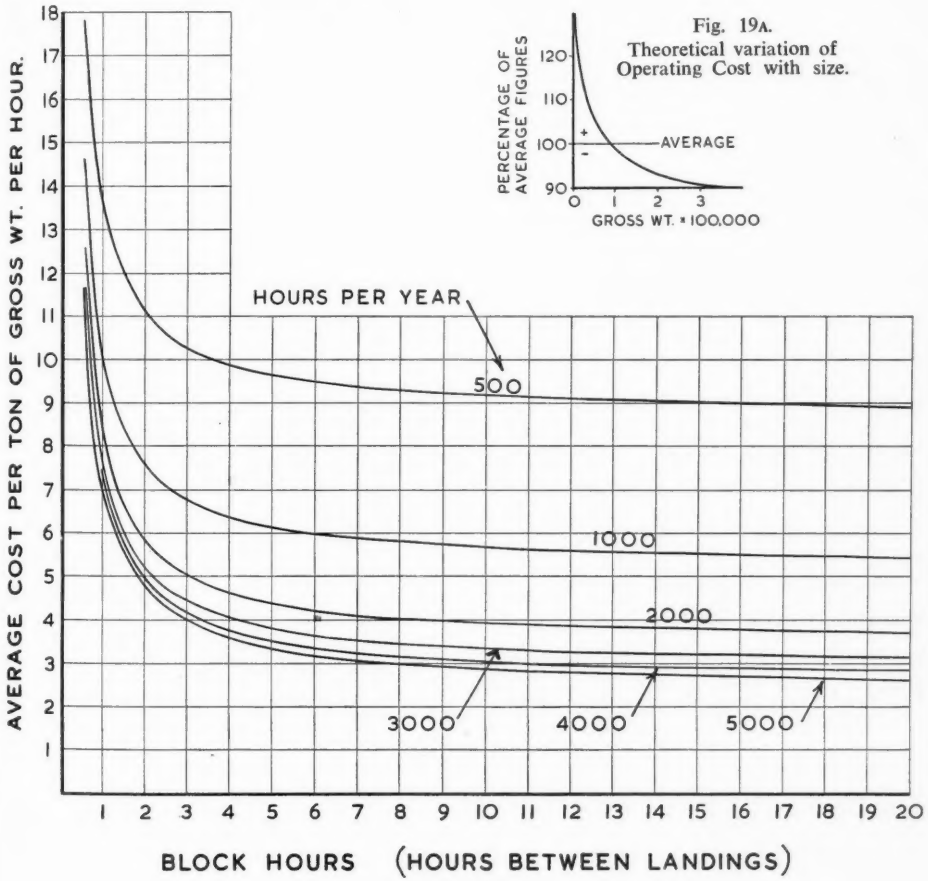



Fig. 19.

Average Operating Costs per ton of gross weight per hour versus Block Hours (Plotted for typical aeroplane of 68,000 lb. gross weight).

cost per unit does not fall significantly for fleets of much more than 12 units.

I have assumed in all the calculations which follow that fleets of about a dozen aircraft are involved, and that in every instance the costs are for scheduled operations.

The curves in Fig. 19 represent total costs per ton of gross weight for an "average" aeroplane. By dividing the totals for any particular utilisation and duration by the payload carried for that duration, the cost per revenue ton per hour can be established. The block speed then leads to the cost for each revenue ton-mile.

These figures are best seen in relation to examples from actual aircraft.

A long dissertation on operating costs makes dull reading. I have endeavoured therefore to cover the problems of operating cost concisely by means of three Tables. I am aware that each and every one of the cost items could be the subject of prolonged discussion—indeed the costs can, and have, formed the subject of complete papers of their own, and, doubtless, will form the subject of many more. For the purpose of this Paper, I have endeavoured to condense the discussion and to present the results in the Tables.

Table XIV sets out the assumptions, composition and factors concerned with the fixed annual costs, together with (in Table XIVA) the results under the individual headings for the seven contemporary aircraft types on the assumptions made.

Tables XV and XVA set out the same data for hourly cruising costs.

Tables XVI and XVIA set out the data for the take-off and landing costs.

Without going into all the details, a number of points under each of the three main heads require discussion and explanation. Throughout I have endeavoured to use the simplest possible approach to the complex problems of cost apportionment, so far as such approach is compatible with reasonable accuracy for a generalised analysis. In each instance I have checked the results gained against figures obtained in practice to ensure that the answers obtained line up with results achieved by efficient airlines in actual operations under European conditions.

### 4.5.2. Fixed Annual Costs.

The fixed annual costs may be defined as the overheads which are not directly influenced by the number of hours or miles flown. They include fleet amortisation and insurance, the costs of headquarters and divisional administration, training and development, and advertising, publicity and sales expenses.

Amortisation costs raise problems of service life and spares for different sorts of equipment. Experience shows that 10 per cent. of airframe spares are a desirable "float"; spares when used being replaced and accounted for under maintenance charges (hourly costs). For most modern types of aircraft a life of seven years is a reasonable assumption, with a residual value of 10 per cent. for disposals sale—the equivalent of a life of 7.75 years with no disposal value.

More spares are required for engines than for airframes. Indeed, 100 per cent. spare engines, plus 50 per cent. engine spares in value, is not at all a high average. In the past, various formulæ have ignored spares and have "written off" engines over a shorter life than the airframe in which they are installed. This assumption does not appear to be justified by experience. Overhauled engines become the equivalent of new engines. At the end of the service life of an aeroplane, the engines may include none of the original components except the type-number tag.

Although there have been a few instances of new types of engines being put into old airframes during commercial service, nevertheless the "wine and bottles" parable applies in the main, and an adequate allowance in maintenance and overhaul costs will cover the rebuilding necessary during overhauls. At the end of the service life of an aeroplane, therefore, there will be behind it almost the same number of spare engines and spares as at the beginning—a reduction of 30 per cent. in spares at the end of the obsolescence period being a maximum reduction in practice.

All this means that the cost of maintaining engines and airframe in operation should be spread over the total revenue hours of the aeroplane's life and the amortisation period of all the components can be considered the full life of the aeroplane.

This conception does not apply to the necessary provision for loss of interest on the capital invested in the fleet. The average value of the aircraft and spares between their initial price and their disposal value is a reasonable basis for this necessary allocation.

Insurance is an important item. Premiums vary between about 3.5 per cent. of the insured value up to more than 10 per cent., according to circumstances. A fair figure seems to be 5 per cent. There are arguments for taking the insured value of the aircraft as its full initial cost; chiefly because of the need to replace, for a shortened amortisation period, any aircraft which may be lost during the life of a fleet. Discussion with operators and with that "patron saint of civil aircraft owners," Captain A. G. Lamplugh, suggests that the best average figure to take for insured value over a fleet life is 80 per cent. of the initial cost.

The remainder of the items under the heading of fixed costs are administrative expenditures which are not directly tied to aircraft costs. Estimation of such overheads is exceedingly difficult and the most widely followed practice has been to assess them as a percentage of other costs. This practice, although the easiest way out in the circumstances, is not really satisfactory. Experience is perhaps a better guide. A detailed examination of the breakdown of these costs for a variety of different airlines shows a general similarity when overheads are compared per ton of gross weight of the fleet operated. High cost operators can be isolated and a favourable trend detected by contrasting operators' records for administrative efficiency with the detailed costs of achieving them. Using such averages as a basis, I have set down the costs per ton of gross weight for these overheads, taking the average of efficient operators, but not necessarily the lowest. I suggest that for a generalised analysis this method gives as fair a figure as can be arrived at for modern practice. The method is not entirely satisfactory and has obvious shortcomings. But it makes possible the estimation of related figures of the correct order on a more precise basis than would be achieved by the addition of a fixed percentage to direct costs.

From these figures it will be seen that the three largest amounts are the engineering base on-costs, the salaries and pensions of the administrative staff, and the airframe amortisation. These items bulk large for a low utilisation, but are much less significant if the annual revenue hours flown reach a respectable figure.

All in all, the fixed annual costs, varying between £3,500 and £4,000 per ton of gross weight for modern aircraft, average around 60 per cent. of the prime cost of the aeroplane per annum. For an annual utilisation of 3,000 hours, the fixed cost will thus average just over £1 per ton of gross weight per hour flown which is between about 12 and 30 per cent. of the total costs for that utilisation, according to stage length. Details are set out in Tables XIV and XIVA.

### 4.5.3. Hourly Cruising Costs.

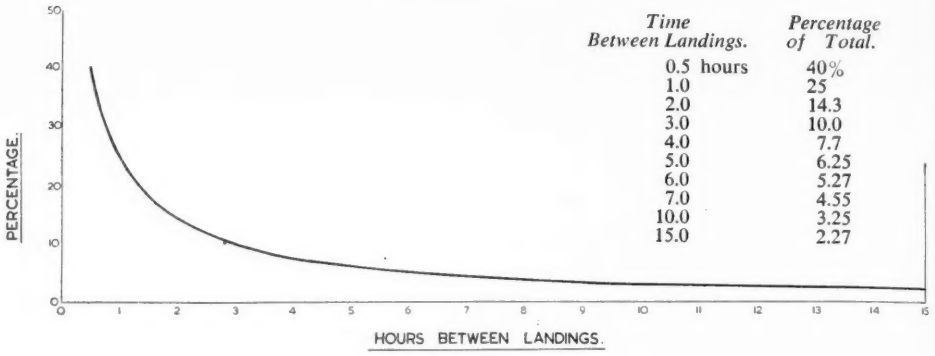
Hourly cruising costs can be defined as the costs incurred per hour over the full hourly utilisation of an aeroplane, at the rate of cost per flying hour, cruising at operating height, ignoring the effect of let down, landing, taxi-ing, take-off and climb.

The biggest items in these direct hourly flying costs are the fuel consumed, engine and airframe maintenance and crew salaries.

The figures which present the greatest difficulty are those for maintenance and overhaul. Current experience indicates that past attempts to assess these items have usually resulted in formulæ giving too optimistic a result. Precise accuracy from any generalised formulæ, however complicated, is almost impossible because of the wide variation of individual maintenance characteristics on the part of different types of aircraft. However, in attempting to reach a generalised basis which will give results consistent with known figures in service, two main factors have to be taken into account—labour and materials.

Labour costs will vary with the efficiency of detailed design for maintenance. As a generalisation, labour costs can be taken as varying with the equipped weight of the airframe and with the cruising power of the engines. Materials costs can be taken, more accurately, as relating to the prime cost of the components. I have assumed that instruments are included with the airframe for purposes of maintenance cost assessment. Propeller and radio maintenance and overhaul are relatively small items and can be dealt with most conveniently and simply by assessment on a basis of cost per £1,000 of prime cost per hour of operation.

An interesting fact is that the total overhaul and maintenance cost of piston engines appears from experience to work out at about £3 17s. 6d. per 1,000 cruising horsepower per hour—the equivalent of about 19.5 per cent. of the prime cost of the engines per 500 hours.




| *Time Between Landings.* | *Percentage of Total.* |
|---|---|
| 0.5 hours | 40% |
| 1.0 | 25 |
| 2.0 | 14.3 |
| 3.0 | 10.0 |
| 4.0 | 7.7 |
| 5.0 | 6.25 |
| 6.0 | 5.27 |
| 7.0 | 4.55 |
| 10.0 | 3.25 |
| 15.0 | 2.27 |

Fig. 20.

Percentage of total costs of maintenance and fuel consumed attributable to each take-off and landing cycle for piston aircraft.

Not enough data has yet been compiled to make possible quotations from experience of similar figures for turbine engines. Much discussion has gone on recently on the subject of probable maintenance costs of turbine types in service. A reasonably optimistic forecast suggests that a fair figure for a developed turbine engine in commercial service would be 15 per cent. of the prime cost per 500 hours; equivalent to a total overhaul and maintenance cost of about £4 12s. 0d. per 1,000 cruising horsepower per hour which is about 20 per cent. greater per cruising horsepower than piston engines, largely on account of the higher initial cost of turbines. Only experience can show how accurate or otherwise these figures may turn out to be but in due course turbines should be substantially cheaper.

A good deal of work remains to be done on these items. For the present, the figures and the basis I have used give results consistent with what is being achieved.

Details of the figures taken can be seen in Tables XV and XVA. The latter shows that for the seven contemporary types, hourly cruising costs per ton of gross weight range between £1 6s. 0d. and £2 8s. 0d. per hour, cruising at height, with the figure of £1 15s. 0d. as a fair average.

For a utilisation of 3,000 hours a year, hourly cruising costs will, therefore, exceed the fixed annual costs, relegating the administrative overheads to a subordinate position. This should be the objective of all airline operators—while doing everything possible, consistent with efficiency, to keep the hourly costs low.

### 4.5.4. Take-off and Landing Costs.

The third main division of the method of cost assessment which I have followed is, perhaps, the most in need of explanation. The heading "take-off and landing costs" includes all those extra costs, over and above the hourly cruising costs, which are incurred in each landing and take-off cycle, from operating height to operating height. They represent the extra-to-cruising cost incurred for every stop.

For instance, suppose the cost for a certain aeroplane, cruising at operating height, is £100 per hour. That is the cost in steady level flight for the individual items detailed under the "hourly cruising cost" heading. Now suppose that, during this specimen hour, the aeroplane descends from its operating height, makes a circuit, lands, taxis in, taxis out, takes-off and climbs again to its operating height. Suppose that the cost for the hour (ignoring any waiting time, which is not counted in the utilisation) goes up from £100 to £370. Then the additional £270 is the take-off and landing cost, made up of the extra fuel used on the climb (less any fuel saved on the descent), and the extra maintenance incurred as a result of the landing operation (including undercarriage wear particularly) and in using full power for take-off. There are also the landing fees, and passenger ground service and, by far the largest item associated with each landing, the station costs incurred in an aeroplane's arrival and departure.

Separation of these costs from those incurred per cruising hour presented a thorny

problem. Practical experience provided the only real guide. By comparing the costs of operating an individual type over a long and a short stage, an approximation was possible. The extra fuel burned per landing presented no great difficulty, nor did station operations or passenger ground service costs, from available data.

After a good deal of research, the curve shown in Fig. 20 was finally arrived at as representing a close approximation of the percentage of the total fuel (for piston types) and maintenance costs associated with the number of hours between landings. Actual figures available for two such widely difficult types as the Dakota and the Constellation were found to agree within about 1.5 per cent.

But, by a long way the largest item under the head of landing costs is that represented by the costs of station maintenance and operations. These costs, which include all the expenses of the operator in running a transit or terminal station, other than the rents and repairs of buildings, amount to between 60 and 75 per cent. of the total take-off and landing costs. Experience supports this figure, which is related directly to the amount of traffic being handled. If this item could be reduced below its present average of some £3 per ton of gross weight per landing, then substantial economies would be possible, particularly in short stage operations. However, the efficient running of an out station, on which the prestige, safety and satisfactory operation of an airline depends, cannot be reduced materially without careful weighing of possible results.

The totals I have quoted are thus representative of present practice.

The full basis reached for take-off and landing costs is set out in detail in Tables XVI and XVIA.

The totals for the seven contemporary types add up to between £3 19s. 4d. and £5 0s. 10d. per ton of gross weight for every landing, with a figure of £4 10s. 0d. per ton per landing a fair average, the smaller types tending to cost a little more, the larger, a little less. Whereas the all-in extra-to-cruising cost of landing and take-off for a Rapide is about £13, that of a Constellation comes out at about £200, and that of the Brabazon I will be some £530. These amounts have an important bearing on the most economic stage length of individual types of aircraft.

There can be no doubt that account has to be taken of these "landing costs" in any generalised operating analysis. For an aeroplane flying 3,000 hours per year and landing every hour, the costs associated with the landing and take-off cycle will amount to about 60 per cent. of the total annual costs. For a similar aeroplane flying 10 hours between stops, the costs associated with landings obviously will be only one-tenth of that amount and comprise only 13 per cent. out of the total, and the total will be reduced by some 55 per cent. These facts are of sufficient importance to be taken into account in deciding whether a new aeroplane for, say, the London-Australia route, should be designed to fly in 2,000 mile stages or 4,000 mile stages, provided that intermediate traffic considerations permit such latitude.

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These, then, are the three main divisions. Totals under each of them have been worked out for the seven contemporary types in Tables XIVA, XVA and XVIA.

We have, therefore, reached the point of being able to assess the economics of the seven contemporary types for two basic variables:—

(*a*) Number of hours of utilisation per year, and

(*b*) Stage length in "hours to be flown" ("block hours").

The derived data on which we have to work is as shown in Table XVII.

The utilisation of every aeroplane in a year includes a number of non-revenue-earning flying hours, either on test flights or positioning. Examination of detailed hourly figures for a number of airlines shows that these hours of "dead flying" amount, on average, to some three per cent. of the total in present conditions. That means that for an annual utilisation of 3,000 hours a total of 2,910 were revenue-earning hours—alternatively that the operating cost per revenue-earning flying hour is three per cent. greater than the absolute cost per hour, *i.e.*, 3,000 revenue hours a year represent a total of 3,090 hours flown. Allowance for dead flying at this scale has been made in what follows.

Taking the three main cost divisions for the seven aircraft and increasing the totals by three per cent. to allow for the dead flying, the total annual costs and the total costs per revenue hour can be set out as shown in Table XVIII.

## TABLE XVII

## SUMMARY OF COST DATA

(Seven contemporary types)

| For Scheduled Operations | 1. Annual Fixed Cost | 2 Hourly Cruising Cost | 3. Take-off and Landing Cost (Per Landing) |
|---|---|---|---|
| 1. RAPIDE III (2.56 tons) | £7,412 (£2,900 p.t.) | £6 3s. 6d. (£2 8s. 0d. p.t.) | £13 0s. 3d. (£5 0s. 10d. p.t.) |
| 2. DOVE I (3.80 tons) | £13,296 (£3,500 p.t.) | £9 1s. 6d. (£2 8s. 0d p.t.) | £18 5s. 4d. (£4 16s. 2d. p.t.) |
| 3. DAKOTA III (12.5 tons) | £33,656 (£2,690 p.t.) | £16 7s. 9d. (£1 6s. 0d. p.t.) | £56 14s. 6d. (£4 10s. 10d. p.t.) |
| 4. AMBASSADOR II (23.2 tons) | £87,970 (£3,790 p.t.) | £42 4s. 3d. (£1 16s. 3d. p.t.) | £98 15s. 8d. (£4 5s. 0d. p.t.) |
| 5. CONSTELLATION IV (47 tons) | £168,350 (£3,580 p.t.) | £72 11s. 6d. (£1 11s. 0d. p.t.) | £200 14s. 0d. (£4 8s. 2d. p.t.) |
| 6. ORION I (89.3 tons) | £332,421 (£3,740 p.t.) | £146 19s. 6d. (£1 12s. 9d. p.t.) | £387 9s.7d. (£4 6s. 10d. p.t.) |
| 7. BRABAZON I (134 tons) | £531,460 (£3,970 p.t.) | £198 5s. 0d. (£1 9s. 6d. p.t.) | £531 19s. 4d. (£3 19s. 4d. p.t.) |

## TABLE XVIII

## REPRESENTATIVE OPERATING COSTS FOR CONTEMPORARY TYPES

| Costs based on 3,000 hours annual utilisation (plus 3 per cent. dead flying) and on scheduled operations with representative overheads.* | | Rapide III | Dove I | Dakota III | Ambass-ador II | Constel-lation IV | Orion I | Brabazon IB |
|---|---|---|---|---|---|---|---|---|
| 1 hour between landings | Total annual costs | £60,800 | £98,100 | £280,000 | —— | —— | —— | —— |
| | Total cost per hour of utilisation | £20.25 | £32.70 | £93.30 | —— | —— | —— | —— |
| 2.5 hours between landings | Total annual costs | £36,600 | £64,300 | £155,300 | £343,000 | £646,000 | £1,274,000 | £1,818,000 |
| | Total cost per hour of utilisation | £12.20 | £21.43 | £51.77 | £114.33 | £215.33 | £424.66 | £606.00 |
| 4 hours between landings | Total annual costs | —— | £55,800 | £129,100 | £297,300 | £552,000 | £1,096,000 | £1,571,000 |
| | Total cost per hour of utilisation | —— | £18.60 | £43.03 | £99.10 | £184.00 | £365.33 | £523.66 |
| 6 hours between landings | Total annual costs | —— | —— | £114,600 | £272,000 | £501,000 | £996,000 | £1,432,000 |
| | Total cost per hour of utilisation | —— | —— | £38.20 | £90.66 | £167.00 | £332.00 | £477.33 |
| 10 hours between landings | Total annual costs | —— | —— | —— | —— | £459,000 | £916,000 | £1,323,000 |
| | Total cost per hour of utilisation | —— | —— | —— | —— | £153.00 | £305.33 | £441.00 |
| 12 hours between landings | Total annual costs | —— | —— | —— | —— | —— | £896,000 | £1,295,000 |
| | Total cost per hour of utilisation | —— | —— | —— | —— | —— | £298.66 | £431.66 |

* The costs must be considered in relation to the payload capacity and hence the revenue of the various aircraft and also in relation to the block-to-block distance covered per hour.

I must emphasise that all the cost calculations are on the assumption that scheduled operations are involved. Operation by non-scheduled charter companies should result in lower figures under the heads of fixed annual costs and take-off and landing costs, chiefly because of less expensive administrative, outstation and traffic services, and, possibly, lower salary and pension scales. The effect on operating costs can be substantial.

4.5.5. ECONOMIC CURVES.

Figures 21 to 27 express the results for scheduled services as hourly "cost curves" for each type, plotting total cost per hour against block hours for utilisations of between 500 and 4,000 hours a year, and from one to 15 hours between landings. These curves show that there is considerable advantage in increasing the utilisation up to 3,000 hours a year (8.25 hours a day) but that the gain in economy thereafter is much less marked. An annual utilisation of 3,000 hours is, therefore, a reasonable target—indeed any substantially higher utilisation may increase costs because of the need to increase overhead provisions.

The cost curves bring out also what is, in my opinion, a fundamental point of which account is not taken in the more familiar direct cost formulæ. It is that the total cost per hour of utilisation will vary, not only with utilisation, but also with the number of hours between landings. For instance, from the average figures set out in Fig. 19 we can see that the costs of operating for five hours between landings at a utilisation of 2,000 hours a year is approximately equal to the cost of operating for 2.5 hours between landings at a utilisation of 4,000 hours a year. The reason is that, for short durations the landing costs are much higher in proportion to the total costs, a factor which may be counterbalanced by the increased payload which can be carried for the shorter duration.

The hourly "cost curves" for the individual types show that the total operating cost per hour varies from a "low" of about £11 per hour for the Rapide operated over its lowest cost stage for 4,000 hours a year (almost unachievable by a small aeroplane), up to a "high" of some £1,473 per hour for the Brabazon I operated uneconomically at its shortest effective stage for only 500 hours a year.

Figures 28 and 29 express these facts in related and generalised form as curves of total cost per hour and of average hourly cost per ton of gross weight for the range of sizes of aircraft, operated at various utilisations.

These two figures bring out the fact that the hourly operating costs of a large aeroplane tend to be less per ton of gross weight than are those of a small aeroplane; a statement which must be qualified by reference to the block speeds achieved. Broadly, the hourly operating cost per ton of gross weight for the largest aeroplane will tend to be about 80 per cent. of the smallest. In other words, at the same utilisation and for the same duration a 100 ton aeroplane, although 20 times bigger than a five ton aeroplane, will be only about 16 times more expensive to operate per hour—a bonus on size resulting, in the main, from the higher proportion of the total represented by such heavy cost items as crew pay in the smaller types.

Taking an arbitrary figure of 3,000 hours a year for all the seven types (which is probably unduly kind to the small, short stage aircraft), and reading off the payload for each type from its "hour chart," I have plotted the operating cost per revenue ton of payload per hour, at 65 per cent. passenger load factor, against duration (block hours). The results indicate the duration at which the lowest cost operation will be achieved for each type—that duration, in most, but not all, instances being the duration at which payload begins to fall off.

So here we have (Fig. 30) the typical economic "U-curves" for the various aircraft, related to duration. The lowest point of the "U" in each instance is the stage duration over which the aeroplane can be flown economically at the lowest fares regardless of wind—a duration ranging from 2.1 hours for the Dove up to 12.1 hours for the Brabazon I.

What these various durations mean in terms of stage miles is, of course, dependent on the cruising speed of the type and on the wind component. For example, on these figures the Constellation has a lowest fare duration of 7.1 hours, which represents a stage length of 1,880 miles in still-air, or 1,220 miles against a 90 m.p.h. head wind.

The economic range of the Constellation can thus be said to lie between about 1,200 and 1,900 stage miles, depending on the route winds.

In Fig. 31 I have plotted the "lowest fare duration" versus size of aircraft on a

## HOURLY COST CURVES

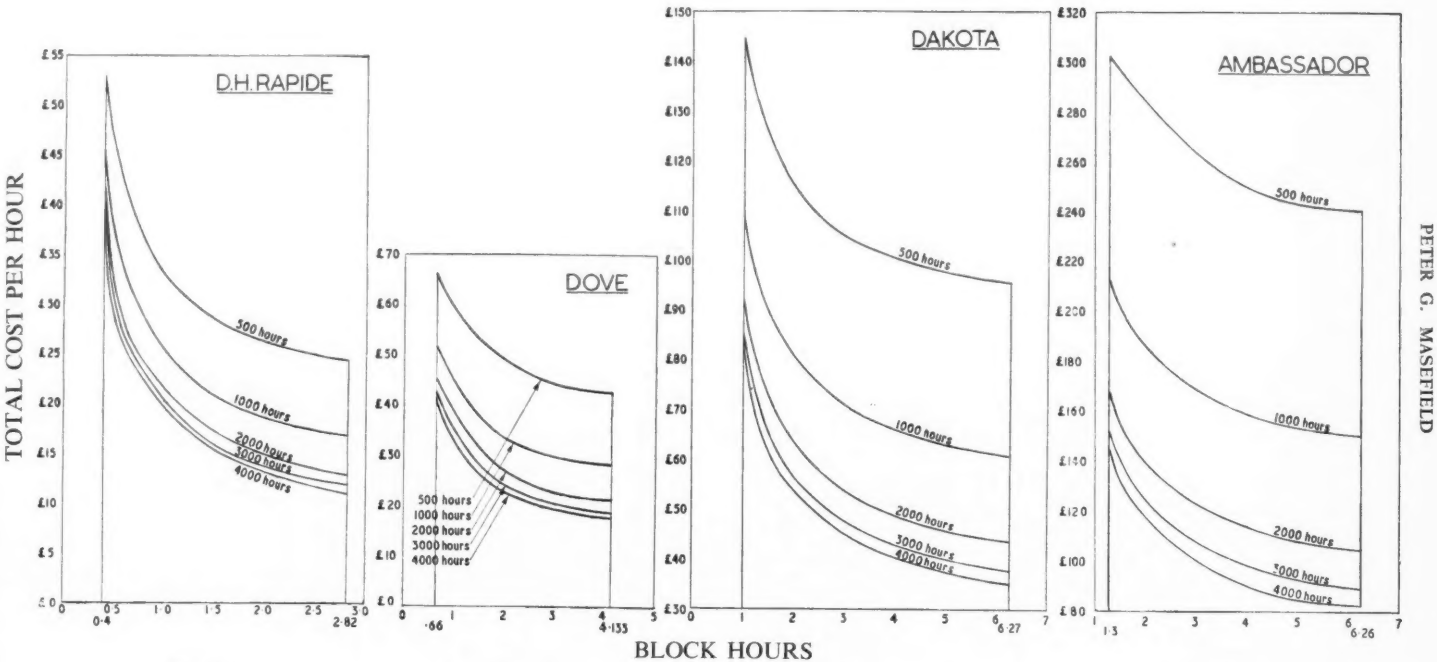



Fig. 21. Fig. 22. Fig. 23. Fig. 24.

## HOURLY COST CURVES

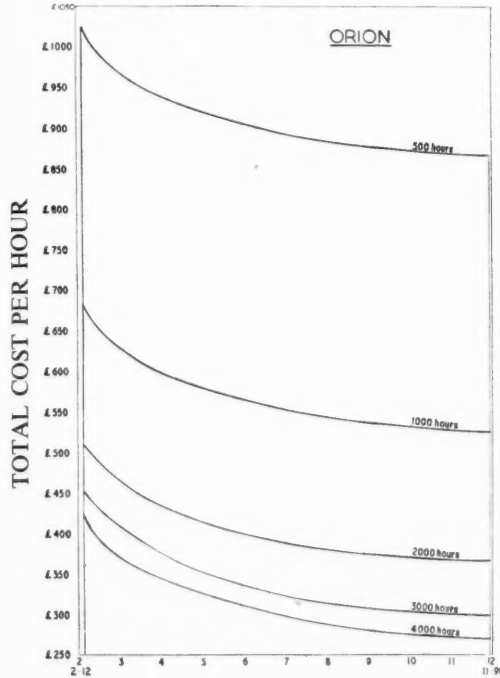



Fig. 25.

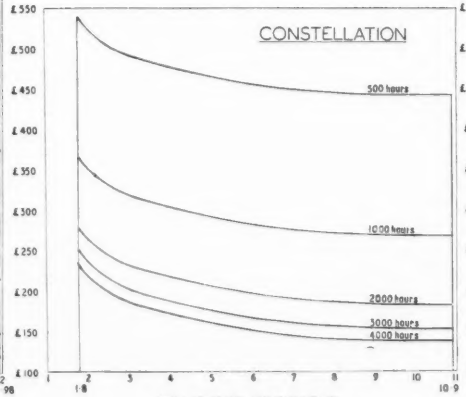



Fig. 26.

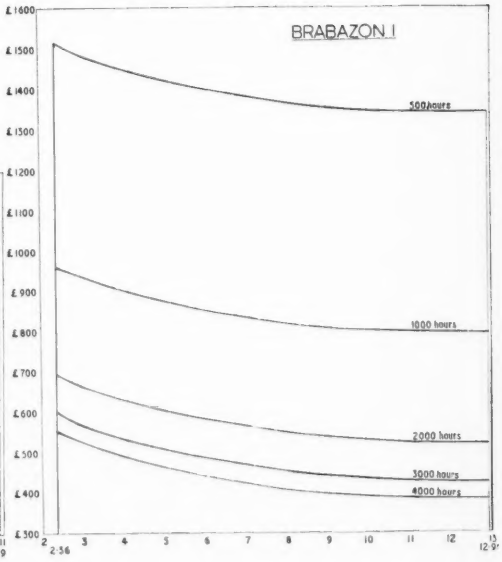



Fig. 27.

generalised basis for contemporary types. Fig. 31 emphasises the fact that the larger the aeroplane the longer the duration over which it has to be operated to achieve the lowest operating cost per ton of payload carried.

So far we have been concerned solely with cost. We now come to the important matter of revenue and profit and loss account.

Revenue is directly proportional to stage length and load factor and dependent on the type of traffic. Present day fares and charges can be broken down into representative figures for various forms of service, the passenger fares varying with the type of service provided; mail and freight rates remaining, on average, substantially constant.

Representative figures can be taken as shown in Table XIX.

The figures in Table XIX are founded on the, rather high, international mail rate of six gold francs per tonne kilometre, and assume a 10 per cent. reduction in half the passenger fares for return tickets. They assume

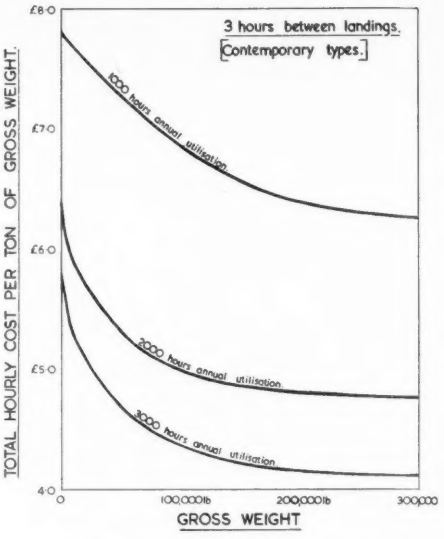



Fig. 29.
Average total hourly cost per ton of gross weight *versus* gross weight.

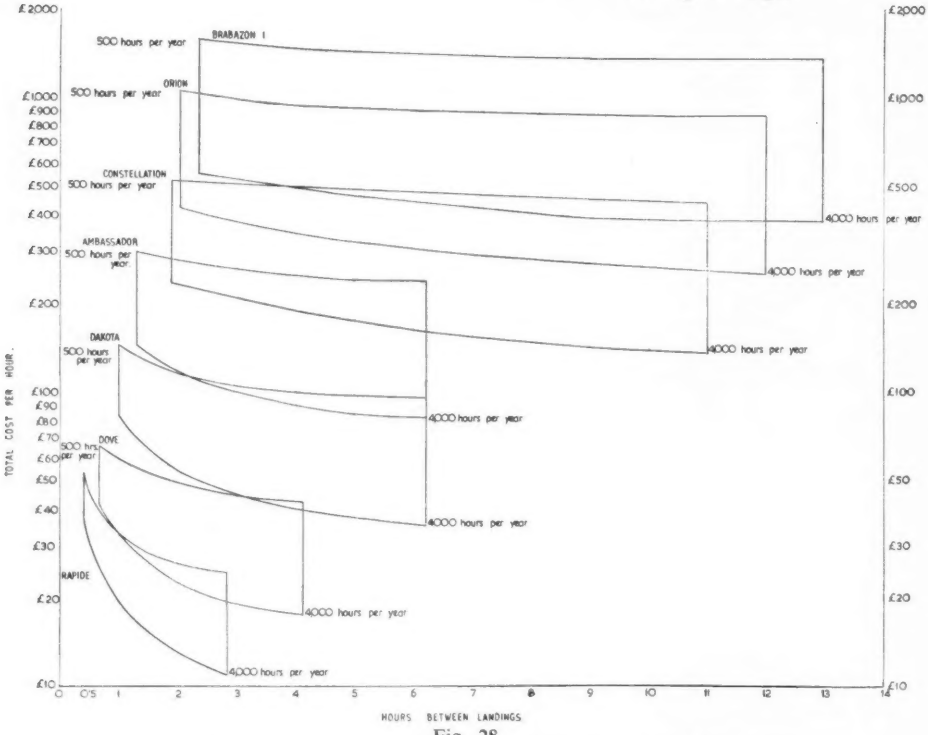



Fig. 28.
Operating cost per hour *versus* hours between landings for various utilisations.

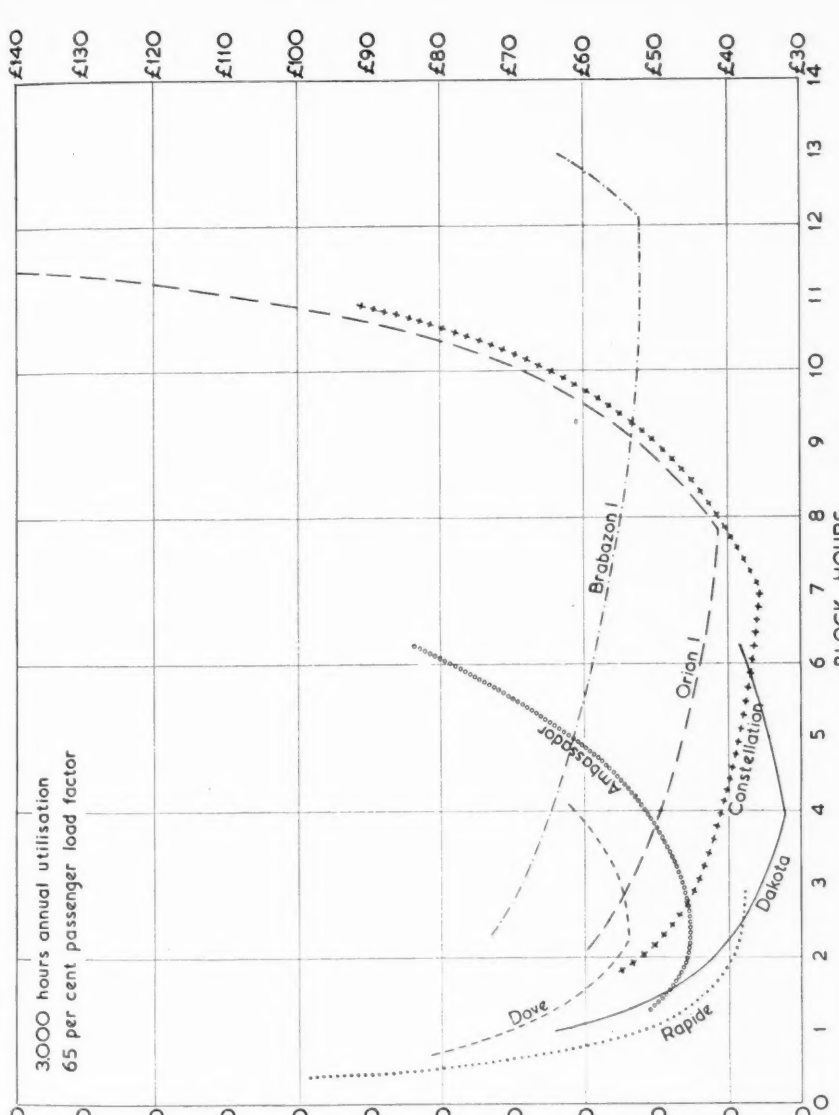



Fig. 30.

Related "U-Curves" of operating cost per revenue ton hour. Contemporary types of aircraft.

average passenger fares representative of European rates, matching a similar basis for costs. American figures are lower, but so are some of the equivalent costs.

Everyone concerned with Air Transport will agree that a reduction of fares is necessary to increase traffic and so decrease costs. In addition less lavish accommodation and 'bus type seating will increase the revenue per ton of passengers. But at present the burden of overheads and the standards of accommodation and of service adopted bring about the average figures quoted. On short stage services in particular there seems room for the streamlining of standards to reduce fares.

Representative figures have been taken for the seven aircraft equipped with their normal passenger seats, plus the amount of mail and freight they can carry with full passenger load. The results then come, on a generalised basis for a normal 65 per cent. passenger load factor, to an average revenue of 5s. 5d. per ton-mile of combined payload for the large aircraft to 6s. 0d. per ton-mile of combined payload for the medium types, and to 8s. 0d. per ton-mile of combined payload for the smaller types. Obviously, so long as the total costs do not exceed these average figures of revenue per ton-mile, the aeroplane will not lose money.

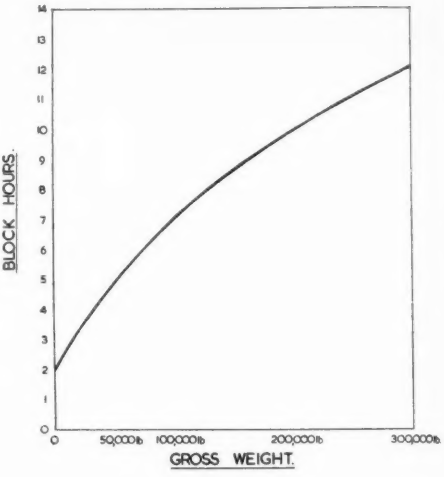



Fig. 31.

Duration for lowest fare *versus* Gross weight. (Trend for contemporary aircraft.) 3,000 hours annual utilisation.

We must remember here again the important fact that while

Costs are proportional to hours flown,
Revenue is proportional to miles covered.

The two can be related only in terms of particular winds and fuel reserves. For

## TABLE XIX

## REPRESENTATIVE REVENUE FIGURES

| Scheduled Operations for: | Long Stage Services | Medium Stage Services | Short Stage Services |
|---|---|---|---|
| Representative aircraft involved | Brabazon Ib<br>Orion I<br>Constellation | Ambassador<br>Dakota | Dove<br>Rapide |
| Average weight of each passenger (with baggage, and consumable stores) | 250 lb. (9 passengers per ton of payload) | 225 lb. (10 passengers per ton of payload) | 200 lb. (11.2 passengers per ton of payload) |
| Average European Passenger Fare per mile | 6 pence (4s. 6d. per ton of passengers per mile) | 8 pence (6s. 8d. per ton of passengers per mile) | 8 pence (7s. 6d. per ton of passengers per mile) |
| Mail rate per ton mile | 16 shillings | 16 shillings | 16 shillings |
| Freight rate per ton mile | 3s. 4d. | 5s. 0d. | 5s. 0d. |
| Combined average rate of revenue per ton mile (at 65 per cent. passenger load factor) | £0.27 | £0.30 | £0.40 |

instance, if an aeroplane costs £100 per hour to operate and flies at a block speed of 200 m.p.h. it will obviously cover 200 miles in one hour in still-air. The revenue would have to be at the rate of £0.5 per mile to make £100 and to "break even."

But if the same aeroplane, flying against a head wind, covers only 150 miles in one hour, then the cost will be the same for that hour, but the revenue would have to be at the rate of £0.66 per mile to make £100 and to "break even." A revenue scale which would show a profit in still-air would thus show a loss against the assumed head wind in this particular case.

These fundamentals can be used to construct "economic curves" of revenue and expenditure to give the relative profit and loss account for various wind and block speed conditions.

The "economic duration curves" in Figs. 32 to 38 show these facts related to the seven selected contemporary types of aircraft.

At representative present day fares these curves reveal that, for the assumptions made and for scheduled services, with a scale of overheads typical of the best present practice, in general there is a slim margin between revenue and expenditure per hour flown, taking into account average route winds.

Indeed, the smaller types have a chance of operating at a profit only in relatively light winds, on the assumptions made. But then small aircraft are more economically used on non-scheduled services, or for executive work, in which the burden of overheads and the base organisation necessary for regular services, can be very much reduced. In such circumstances of lower proportional overheads the small types will show up well.

On the figures taken, the Ambassador will show a profit for durations of between about 1.5 and 5 hours, even against a 30 m.p.h. wind, with the best margin of profit at 3.2 hours duration. The duration can be related to stage length from the hour charts.

The Constellation shows itself to be capable of a profit even against a 90 m.p.h. wind operated for durations between 3.25 and 8.75 hours—an indication of the quality and economic flexibility of the aeroplane. Its most economic duration is 7.1 hours.

The Brabazon has similar potentialities over longer ranges. Even against a 90 m.p.h. wind it should be capable of a profit for durations of between 7 and 12.75 hours, extending to 3.5 and nearly 13 hours in still-air. Its most economic duration is just over 12 hours.

As I have already remarked, the stage length appropriate to any duration in "block hours" for any wind component can be read off the hour charts and applied to these "economic duration curves." From them can be read the operating cost and the revenue appropriate to the duration and wind component—the ratio between revenue and expenditure depending on the miles covered in the particular block hours which, in their turn, will depend on the wind.

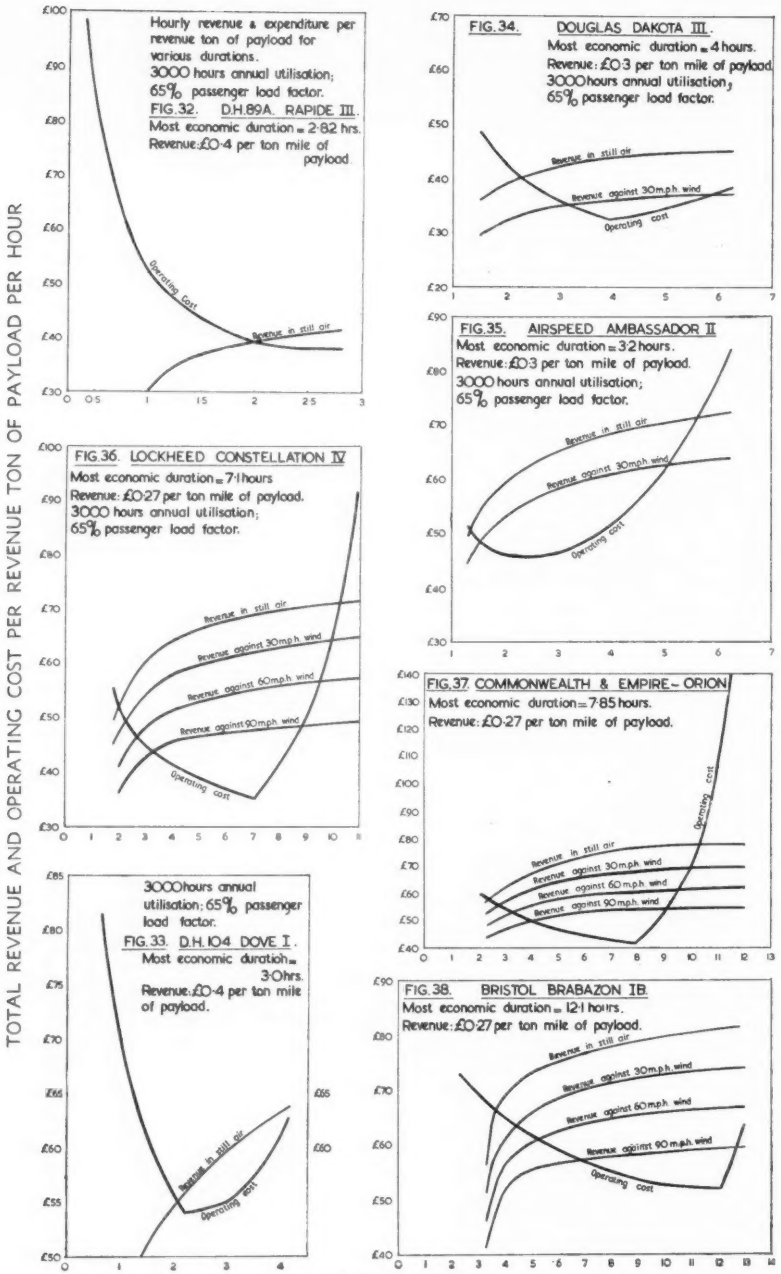
Although the "hour charts," read in conjunction with the "economic hour curves," give all the answers for any selected stage length and wind condition, as a simplification of the approach I have plotted, in Fig. 39, the operating costs and revenue of the seven aircraft related to stage length in just one condition—still-air. Such an approach shows the slower aircraft to particular advantage, but gives, probably, a more easily assimilated series of results for a quick appreciation.

Figure 39 shows that, if adequate traffiic is offering to furnish a 65 per cent. passenger load factor at frequencies which will result in a reasonable utilisation, the Ambassador is the most economic of the aircraft reviewed from 215 to 600 miles stage length in still-air. Despite its higher cost compared with the Dakota, the Ambassador is cheaper to operate than is the Dakota for each ton of payload or for each passenger, over all stage lengths. The higher the head wind the greater the Ambassador's advantage.

For stage lengths of between 600 and 2,350 still-air miles the Constellation offers the most economic proposition of the types considered. The Brabazon I has the field on its own from 2,350 miles up to its maximum of 3,920 miles stage length in still-air.

These curves bring out also that for scheduled operations in still-air and for the assumptions taken, profits can be made on stage lengths approximately as follows:—

Rapide—190 to 290 miles stage length.
Dove—270 to 650 miles stage length.
Dakota—310 to 980 miles stage length.
Ambassador—220 to 1,270 miles stage length.
Constellation—335 to 2,700 miles stage length.
Orion I—455 to 2,900 miles stage length.
Brabazon I—750 to 3,920 miles stage length.


Hourly revenue & expenditure per revenue ton of payload for various durations.
3000 hours annual utilisation;
65% passenger load factor.
FIG.32. D.H.89A. RAPIDE III.
Most economic duration = 2·82 hrs.
Revenue: £0·4 per ton mile of payload.
Operating cost
Revenue in still air
FIG.34. DOUGLAS DAKOTA III.
Most economic duration = 4 hours.
Revenue: £0·3 per ton mile of payload.
3000 hours annual utilisation;
65% passenger load factor.
Revenue in still air
Revenue against 30 m.p.h. wind
Operating cost
FIG.35. AIRSPEED AMBASSADOR II
Most economic duration = 3·2 hours.
Revenue: £0·3 per ton mile of payload.
3000 hours annual utilisation;
65% passenger load factor.
Revenue in still air
Revenue against 30 m.p.h. wind
Operating cost
FIG.36. LOCKHEED CONSTELLATION IV
Most economic duration = 7·1 hours
Revenue: £0·27 per ton mile of payload.
3000 hours annual utilisation;
65% passenger load factor.
Revenue in still air
Revenue against 30 m.p.h. wind
Revenue against 60 m.p.h. wind
Revenue against 90 m.p.h. wind
Operating cost
FIG.37. COMMONWEALTH & EMPIRE - ORION
Most economic duration = 7·85 hours.
Revenue: £0·27 per ton mile of payload.
Operating cost
Revenue in still air
Revenue against 30 m.p.h. wind
Revenue against 60 m.p.h. wind
Revenue against 90 m.p.h. wind
3000 hours annual utilisation; 65% passenger load factor.
FIG.33. D.H.104 DOVE I.
Most economic duration = 3·0 hrs.
Revenue: £0·4 per ton mile of payload.
Revenue in still air
Operating cost
FIG.38. BRISTOL BRABAZON 1B.
Most economic duration = 12·1 hours.
Revenue: £0·27 per ton mile of payload.
Revenue in still air
Revenue against 30 m.p.h. wind
Revenue against 60 m.p.h. wind
Revenue against 90 m.p.h. wind
Operating cost
TOTAL REVENUE AND OPERATING COST PER REVENUE TON OF PAYLOAD PER HOUR
BLOCK HOURS

Figs. 32-38.

Economic Duration Curves showing hourly revenue and cost per ton of payload for selected contemporary aircraft. (Total revenue and operating cost per revenue ton of payload per hour plotted against block hours. Curves based on scheduled services.)

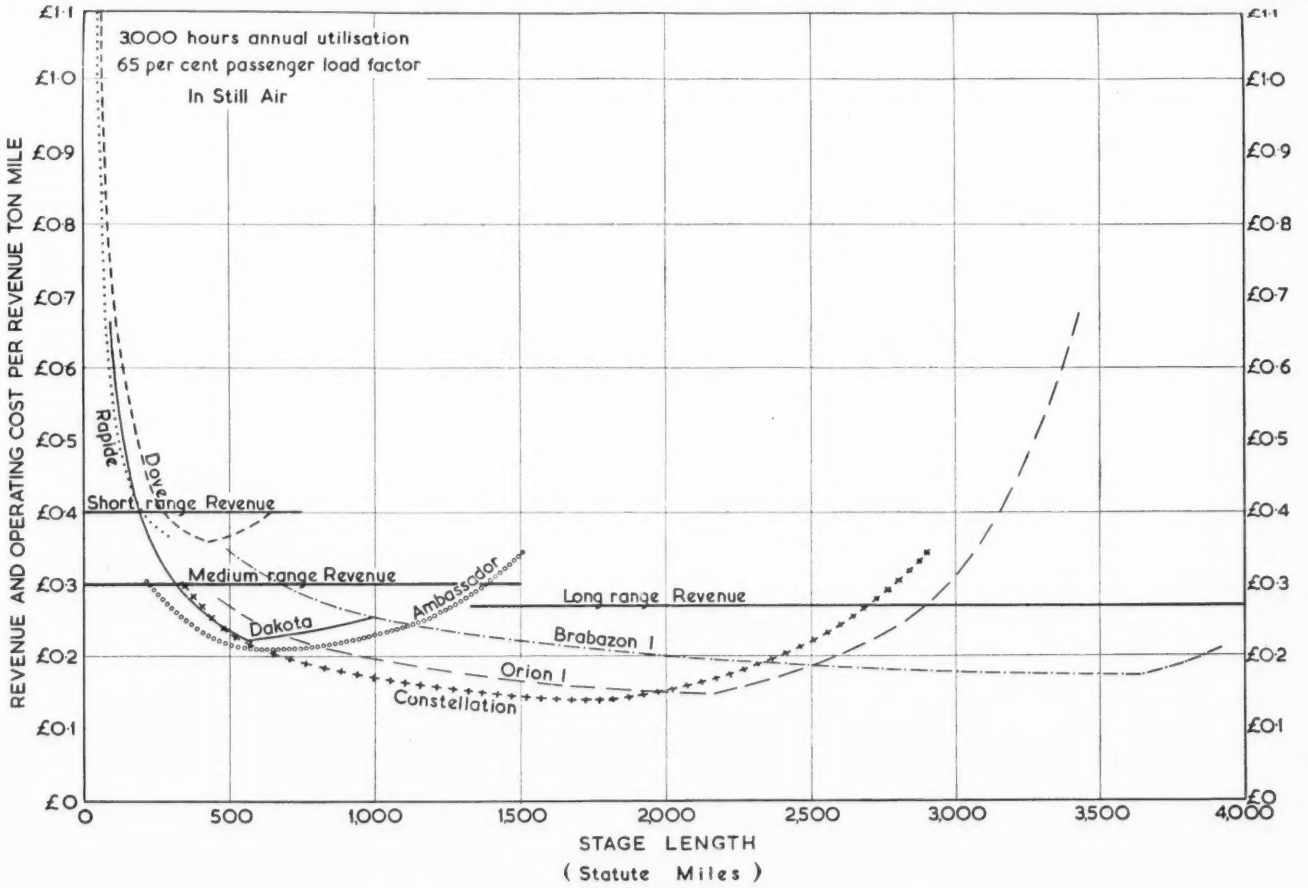



Fig. 39.
Economic Stage Length Curves. Contemporary types of aircraft.
(The lowest point of the curve for each aircraft indicates the stage length at which it achieves its most economic performance in still air.)

Against headwinds, both the amount of revenue and the economic stage length will be reduced. This effect is shown on a generalised basis in Fig. 40 in which the most economic stage length (the stage length with the biggest favourable gap between revenue and cost) has been related to gross weight for various winds, the results being typical for present-day commercial aircraft at present-day cruising speeds.

Thus, an aeroplane of 100,000 lb. gross weight, on contemporary standards, has a most economic stage length of some 1,500 statute miles in still-air, reduced to 900 miles against a 90 m.p.h. wind. Similarly, the most economic stage length of a 200,000 lb. aeroplane will lie between 2,300 miles and 1,500 miles in the present state of the art with conventional piston engines. As a corollary, if a requirement is to operate over, say, a 2,000 stage length against a 60 m.p.h. headwind then, from Fig. 40, the most economic size of aeroplane for the job, traffic permitting, is 240,000 lb.

Then, from Fig. 17, we find that the capacity payload of such an aeroplane will be about 27,000 lb. which can be carried for the equivalent 2,600 miles still-air stage length.

In the present state of the art and taking into account average winds but not the amount of traffic offering, the most economic size of aircraft for a stage length of:—

100 miles non-stop is about 4,000 lb. (1.78 tons).

500 miles non-stop is about 18,000 lb. (8 tons).

1,000 miles non-stop is about 70,000 lb. (31 tons).

2,000 miles non-stop is about 200,000 lb. (89 tons).

3,000 miles non-stop is about 400,000 lb. (179 tons).

3,500 miles non-stop is about 500,000 lb. (223 tons).

That is, assuming in each instance that the ratio of operating-frequency to traffic offering is reasonable.

Relating these figures back to the seven selected contemporary types we can find directly the most economic stage lengths over which each of the contemporary aircraft can be operated in conditions varying from still-

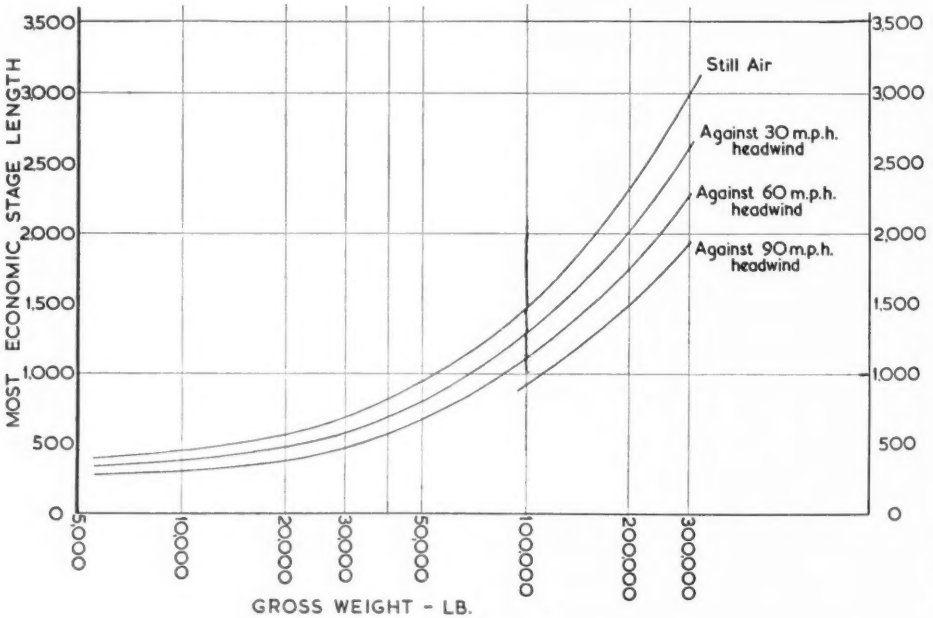



Fig. 40.
Most Economic Stage Length related to Gross Weight. Trend for contemporary aircraft.

## TABLE XX

| Aircraft | Most economic stage length (In Still Air) | Block speeds achieved (Against 60 m.p.h. Head Wind) |
|---|---|---|
| 1. Rapide | Between 290 and 144 statute miles | (103 to 51 m.p.h.) |
| 2. Dove | Between 444 and 288 statute miles | (148 to 96 m.p.h.) |
| 3. Dakota | Between 600 and 390 statute miles | (145 to 95 m.p.h.) |
| 4. Ambassador | Between 700 and 555 statute miles | (219 to 174 m.p.h.) |
| 5. Constellation | Between 1,880 and 1,440 statute miles | (225 to 203 m.p.h.) |
| 6. Orion I | Between 2,170 and 1,760 statute miles | (276 to 224 m.p.h.) |
| 7. Brabazon I | Between 3,630 and 3,000 statute miles | (300 to 248 m.p.h.) |

air to a 60 m.p.h. head wind. They are given in Table XX.

Figure 41 carries the business a stage farther and shows the lowest cost per revenue ton mile which can be expected over various stage lengths in still-air, if the most suitable size of aircraft is used, based on contemporary practice. Break-even fares could be reduced to a minimum of about threepence per passenger mile.

This figure brings out the illuminating fact that on the assumptions made the best stage length to fly for the lowest operating cost per ton mile (but not necessarily the highest profit or least loss) lies between about 1,800 and 2,000 stage miles in still-air, using an aeroplane of about 150,000 to 200,000 lb. gross weight .

But that is not, of course, the whole story. When revenue is taken into consideration a profit and loss account can be drawn up showing the trend over various stage lengths using the theoretically most economic size of aircraft for each stage.

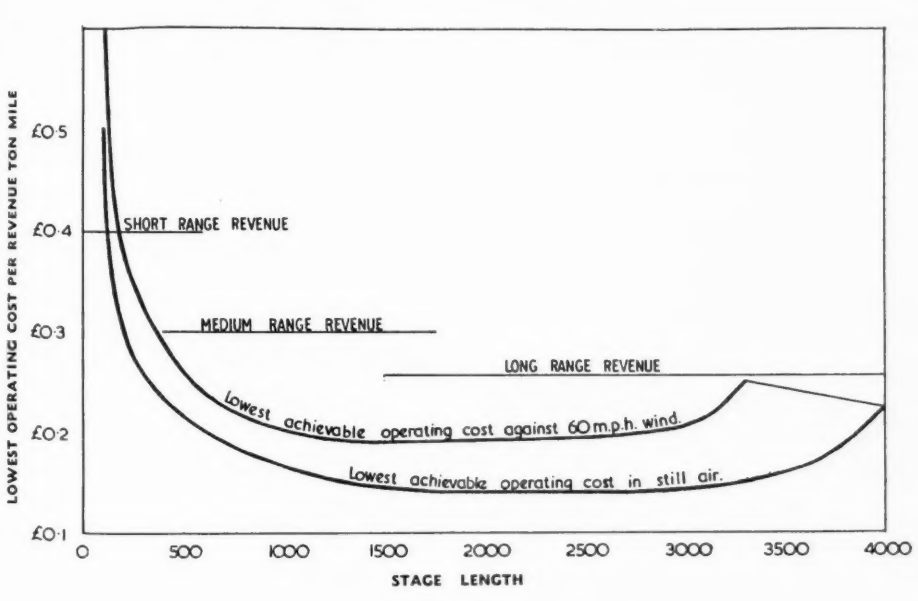



Fig. 41.

Lowest achievable operating cost for various stage lengths using the theoretically best size of aircraft for each stage length. (Contemporary standards.)
3,000 hours annual utilisation, 65 per cent. pasenger load factor.

Such a result is plotted in Fig. 42. The fact that revenue varies with the type of service exerts a major influence. Operations over stages of between 250 and 600 miles with aircraft of between about 10,000 lb. and about 30,000 lb. gross weight are likely to yield the best economic results of any regular services. Stage lengths between 1,000 and 1,300 miles long are also in a good economic field for aircraft of around 80,000 lb. gross weight, while appropriate sizes of aircraft, efficiently operated, should ensure profitable operations up to stage distances of about 3,500 miles—and more. Indeed the fundamental fact is—match your aeroplane to your stage length if efficient results are to be gained. A glance back at Fig. 39 will show how losses must inevitably result if aircraft are operated over inappropriate stages.

Although the conclusions on relative stage length are fundamental, I must stress here again that the precise figures for cost are significant for only the typical conditions selected, namely, 3,000 hours annual utilisation on scheduled services, a 65 per cent. passenger load factor and overheads for the most economic stage length running at a rate between 40 and 50 per cent. of total costs. Appropriate corrections would have to be applied for any other utilisation or passenger load factor—or for any variation in the basic assumptions.

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## 4.6. SUMMING UP (CONTEMPORARY TYPES).

I have now worked through the performance and economic aspects of the seven selected types of contemporary transport aircraft which cover the range of sizes from 2½ tons to 134 tons. Those types, which are representative of the best practice extant in 1948 in their various classes, serve as a basis for some general conclusions.

The most important conclusion, I think, concerns operating costs and revenue. It is

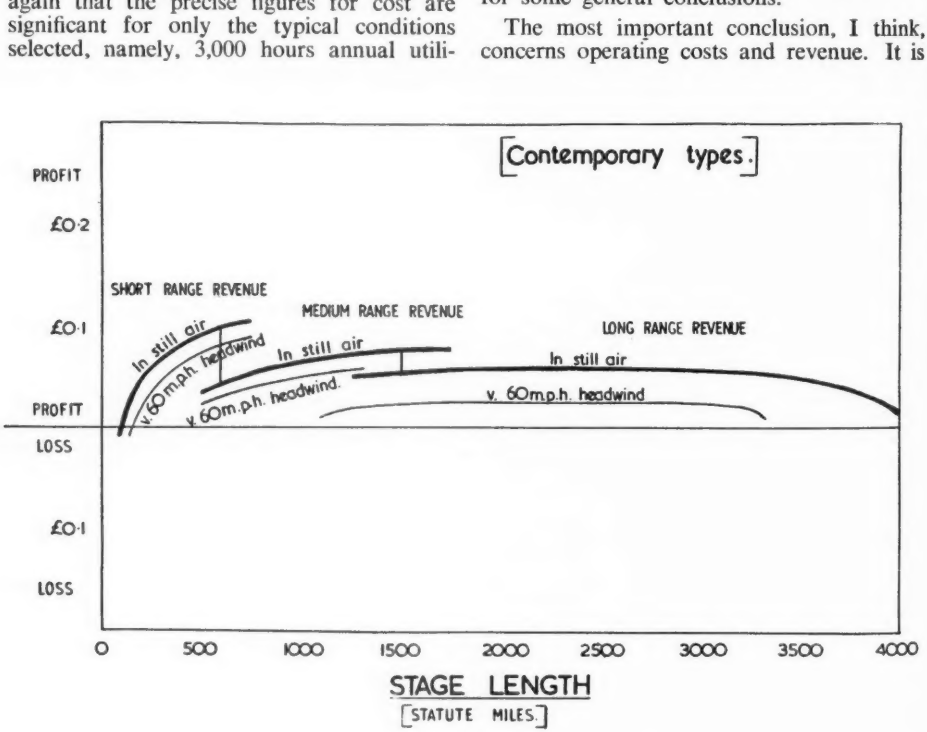


Fig. 42.

Profit or Loss *v.* Stage Length. (Using theoretically best size of aircraft for each stage length.)
Based on: 3,000 hours annual utilisation, 65 per cent. passenger load factor.

that, provided an aeroplane is matched to a route in terms of the most economic size for the stage length to be operated, taking into consideration the prevailing winds, and provided that the aeroplane is flown at a reasonably high utilisation, Air Transport, even with present types of aircraft—I mean such present types as are commercially efficient—can be made to run at a profit at the present (high) fares. This assumes no subsidy and overheads at rates typical of present day practice on the part of the lower cost operators.

The figures bring out, however, the precarious margin between profit and loss even in the circumstances representative of the best airline operational practice of to-day. They explain why large losses can be contracted almost unawares.

A prominent reason for the narrow boundary between profit and loss lies in the overheads and in the operation of stage lengths unsuited to the sizes of aircraft used. The typical figures for scheduled operations which are set out in this analysis include overheads at a rate of between 40 and 50 per cent. of the total costs—the higher figure being for short stages. Were the magic figure of 33 per cent. overheads achieved—as has been done by the one prominent international airline which is operating at a profit—then the picture becomes much more rosy.

The moral is—commercial flying must not be "grounded" by its administrative overheads.

I should emphasise that figures for cost per ton mile or per hour as estimated here must not be compared with similar figures for the same or for other aircraft estimated on different assumptions. These figures devolve from the assumptions made — different assumptions naturally lead to different figures. I use the results here therefore as a basis for generalised conclusions rather than as quantitative accounts. The precise operating costs for any aeroplane over any stage length can be assumed only in relation to the particular conditions of the route and of the operator concerned.

Subject to these provisos the results are encouraging. Although weighed down with overheads and difficult operating standards the Brabazon Ib, for instance, shows itself capable of making a profit operating westbound across the North Atlantic against the average head wind, which is 52 m.p.h. at 35,000 feet. Eastbound, with prevailing tail winds, it should do better still. The picture will not be quite so favourable as at first appears because, on the relatively few occasions on which one landing will be necessary intermediately, westbound, the aeroplane will have to operate over one stage length a good deal short of its economic distance. Developments in pressure pattern flying may help here.

The Ambassador and the Constellation are also potentially profitable propositions, even without subsidy, provided that they are operated efficiently over stage lengths to which they are suited. The same can be said of the Dove, although small aircraft of this sort are clearly intended more for the operation of non-scheduled and feeder routes than for regular airline services.

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In reaching the conclusion of this portion of the Paper, dealing with contemporary standards, four points can sum up the discussion. They are:—

1. Reduce overheads.
2. Increase utilisations.
3. Maintain standards.
4. Match aircraft to routes.

Such things are more easily said than done. When achieved, profits are possible—at present fares—using the best contemporary types of aircraft.

By cutting down overheads, increasing utilisations and matching aircraft to routes, substantial savings in operating costs should be possible, compared with present standards. Such savings ought to be used to reduce fares well below their present high levels, opening up Air Transport to a much wider traffic potential. Even with contemporary types we should then see a wide expansion of civil aviation—economically.

But what of the future? For, in the words of Disraeli: "The present interests me more than the past; the future more than the present."

# Part III

## 5. OPERATING ANALYSES (FUTURE POSSIBILITIES)

### 5.1. THE PROBLEM OF FUTURE POWER PLANTS.

One of the outstanding questions of the hour is the form of power plant which is likely to prove most satisfactory for various classes of transport aircraft for various stage lengths.

"Most satisfactory" can, of course, cover a multitude of desirable features. But there is one pre-eminent requirement which should always be kept in view. That is that the combination of airframe and engine considered should be capable, first of covering its direct operating costs plus overheads and, having done that, of flying as fast as possible.

Different forms of power plant will, obviously, result in different operating costs per hour and per mile. The cheapest is not necessarily the best. Higher speeds, increased reliability, superior regularity, greater comfort, increased safety—all may cost more, but all may be worth more as sales propositions. Higher operating costs, if combined with superior attraction, will result in increased revenue. The important thing is that the cost and the revenue that can be attracted should be kept in balance.

Just what different forms of modern power plant can mean in cost and attractability over various stage lengths has never been fully assessed. Indeed "attractability" is an intangible, which does not easily lend itself to quantitative estimation.

From the point of view of commercial operations, the questions which stand out in considering any new form of power plant are:—

*What will it cost per annum*—when all considerations have been taken into account; chiefly, consumption, maintenance and overhaul, and amortisation?

*What are its powers of earning revenue*—remembering that a fast aeroplane can pack into a year more revenue miles per hour of utilisation than can a slower aeroplane?

*What are its qualities in bad weather*—what sort of fuel allowances and reserves (cutting into available payload) will be necessary; how will it perform in turbulent or icing conditions; in fact, can it maintain reliability and regularity economically all the year round?

It is on these latter qualities that so much remains to be learned about the newer forms of power plant.

I cannot—and do not pretend to—know all, or even most, of the answers to these aeronautical conundrums. Time and experience alone can show what can be achieved. But it is possible to survey some of the qualities which are in prospect from different types of engine. Accordingly, I have examined some of the operational possibilities of three types of modern power plant applied to hypothetical airframes in comparison with the standard piston engine—

(i) The "compound" piston engine.
(ii) The "propeller-turbine" engine.
(iii) The "plain jet" engine.

So that the possibilities of these various power units can be seen in relation to both short and long range projects, I have based the analyses on two families of aeroplane—first on a 12½ ton twin-engined transport, powered with known engines, second on developments of the mythical Orion, powered with hypothetical engines.

### 5.2. THE TWIN TRANSPORTS.

Taking the shorter stage types first, I have examined the possibilities of four hypothetical twin-engined aircraft, each of 28,000 lb. gross weight. The four Twin Transports analysed are as follows:—

1. "Twin Merlin Transport" (two 1,500 b.h.p. Rolls-Royce Merlin 35 engines).
2. "Twin Merlin Helicopter" (two 1,500 b.h.p. Rolls-Royce Merlin 35 engines).
3. "Twin Dart Transport" (two 1,500 e.h.p. Rolls-Royce Dart prop-turbine engines).
4. "Twin Derwent Transport" (two 3,900 lb. s.t. Rolls-Royce Derwent plain-jet engines).

All these aircraft are assumed to have the same gross weight of 28,000 lb. (12.5 tons), which is in fact the same as that of the elderly Dakota whose performance has been analysed earlier. The important difference

is that the "Twin Transports"—like the Ambassador—will meet I.C.A.O. "one engine out" requirements at full load whereas the Dakota will not. All four aircraft have been given the same take-off power; 3,000 b.h.p. for the propeller types, 7,800 lb. of static thrust for the plain-jet version. Hence all will have approximately the same runway requirements for take-off and landing (2,000 ft. distance to attain 50 ft. at full load on full power)—except, of course, the helicopter. The helicopter, incidentally, has been added because so little comparative analysis has been made of the large helicopter that its possible place in the scheme of things for short stage operations is still nebulous. I have included only a piston-powered helicopter because so little is known, as yet, about helicopters whose blades are spun by athodyds or some other form of jet thrust. In the long run, jet helicopters may turn out to be the best bet. Again, time will show.

All the fixed wing aircraft compared are thus of the same weight, power loading and wing loading. Although at first sight an attractive method of comparison might appear to be to take a fixed payload for a fixed stage length, and then determine the size of aeroplane required to perform those functions at different speeds with the different types of power plant, on further examination, the preferable method seems to be to take a fixed size of aircraft and to determine the comparative payload/range/speed/cost characteristics with the various forms of power plant for similar take-off performance. The reasons for this are:—

(*a*) A fixed payload can be computed only for one stage length in one assumed condition of wind and with one set of allowances and reserves.

(*b*) If a comparison were made for one fixed payload to be carried over one range, then the comparison would be accurate only for that one set of assumed conditions. For all other conditions, the payload and block speed would vary at different rates.

(*c*) A comparison of different types of engine of the same order of power in one aeroplane gives results which are preferable because they show up variations in equipped weight, cruising speed, consumption, and so on, more directly.

(*d*) Finally, modern aeroplanes have, unfortunately, to be designed to fit a pre-determined length of runway. A comparison between various engines of similar take-off thrust in aeroplanes of similar weight and wing area, therefore, will give similar take-off performance — modified somewhat in tropical conditions because of the aggravated influence of high temperatures on turbines.

I have arbitrarily imposed very stringent take-off requirements on the fixed wing twin transports to enable them to operate with an adequate "accelerate-stop" performance from runways only 3,600 ft. (1,200 yards) long. Were this requirement relaxed their gross weight could be allowed to go up considerably, making the aircraft more economic because of the additional payload which could be carried. The stringent runway standards handicap the aircraft economically, but are a likely requirement for such types in the future in order to reduce aerodrome expenses for short haul work.

### 5.2.1. Weights and Performances.

The assumed weights of the four aircraft are set out in Table XXI. Their performance characteristics are in Table XXII. I must express here my thanks to Rolls-Royce Ltd. for assistance in making sure that the hypothetical aircraft represent reasonable attainments with the selected power plants. If anything, I think that the performances quoted may be considered conservative.

At the same time, I trust that I may be acquitted of favouritism in selecting for comparison the products of one firm. I have done so for two reasons: firstly, because Rolls-Royce happen to have three different types of engine in the same power class; secondly, because a comparison of the different products of one manufacturer avoids invidious contrasts between competing firms.

A word here about the power plants:—

The Merlin 35 is a simplified version of the long tried Merlin engine. It is intended for comparatively short-haul work at moderate heights. For this reason it has a single-speed, single-stage, centrifugal supercharger. Its take-off rating is 1,500 b.h.p. for a dry weight of 1,520 lb. and a weight of 2,850 lb. installed as a complete power plant.

The Dart is a relatively small propeller-turbine engine with a two-stage centrifugal compressor and two-stage turbine. The Dart has recently flown for the first time and is intended as an alternative, with the equally interesting Armstrong Siddeley Mamba axial, for the Vickers-Armstrongs Viscount and the Armstrong Whitworth Apollo. In developed form, I have assumed that the

## TABLE XXI

## WEIGHT ANALYSIS
## TWIN-ENGINED SHORT-RANGE AIRCRAFT

| | Twin Merlin Transport (two standard piston engines) | Twin Merlin Helicopter (two standard piston engines) | Twin Dart Transport (two prop-turbine engines) | Twin Derwent Transport (two plain jet engines) |
|---|---|---|---|---|
| 1. Structure weight ... ... lb. | 8,300 | 9,615 | 8,450 | 8,500 |
| 2. Power plant and systems weight lb. | 6,200 | 6,270 | 3,900 | 4,100 |
| 3. Operating equipment weight lb. | 2,350 | 2,350 | 2,350 | 2,350 |
| 4. Passenger equipment weight... lb. | 1,750* | 2,000† | 2,000‡ | 2,000‡ |
| 5. Empty weight... ... ... lb. | 18,600 | 20,235 | 16,700 | 17,050 |
| 6. Cockpit crew ... ... ... lb. | 600 | 600 | 600 | 600 |
| 7. Cabin crew ... ... ... lb. | 200 | 200 | 200 | 200 |
| 8. Fixed stores ... ... ... lb. | 280 | 280 | 280 | 280 |
| 9. Unusable fuel ... ... lb. | 170 | 170 | 250 | 400 |
| 10. Basic weight ... ... ... lb. | 19,850 | 21,485 | 18,030 | 18,530 |
| 11. Maximum oil capacity ... lb. | 350 | 240 | 60 | 50 |
| 12. Equipped weight ... ... lb. | 20,200 | 21,725 | 18,090 | 18,580 |
| 13. Maximum usable fuel capacity lb. | 4,870 | 3,315 | 7,000 | 6,550 |
| 14. Corresponding payload ... lb. | 3,000 | 3,000 | 3,000 | 3,000 |
| 15. Usable fuel with capacity payload ... ... ... ... lb. | 0 | 0 | 2,130 | 1,680 |
| 16. Capacity payload ... ... lb. | 7,870 | 6,315 | 7,870 | 7,870 |
| 17. Disposable load ... ... lb. | 7,870 | 6,315 | 10,000 | 9,550 |
| 18. Gross weight ... ... ... lb. | 28,070 | 28,040 | 28,090 | 28,130 |
| 19. Pre-flight fuel allowances ... lb. | 70 | 40 | 90 | 130 |
| 20. Maximum take-off weight ... lb. | 28,000 | 28,000 | 28,000 | 28,000 |
| 21. Maximum landing weight ... lb. | 28,000 | 28,000 | 28,000 | 28,000 |

* Non-pressurised. † Bus-type seating for additional passengers. ‡ Pressurised.

Dart gives for take-off a total of 1,360 shaft h.p. and 365 lb. static thrust (the equivalent of 1,500 b.h.p.) for a dry weight of 980 lb. and a weight of 1,650 lb. installed.

The Derwent V is familiar in the Meteor fighter. Applied here to a civil transport, I have assumed a take-off thrust of 3,900 lb. (equivalent to 1,500 b.h.p.), which should be within the capabilities of the engine with water-methanol injection. The Derwent is thus the smallest jet engine which will do the job. I have deliberately selected the smallest engine in efforts to improve economy. Its dry weight is 1,250 lb. and it weighs 1,750 lb. installed.

For the purposes of this Paper, I have assumed prime costs of complete power plants (with all cowlings, mountings, acces-

## TABLE XXII

## COMPARATIVE PERFORMANCE DATA
## TWIN-ENGINED SHORT-RANGE AIRCRAFT

| | Units | Twin Merlin Transport (two standard piston engines) | Twin Merlin Helicopter (two compound piston engines) | Twin Dart Transport (two prop-turbine engines) | Twin Derwent Transport (two plain jet engines) |
|---|---|---|---|---|---|
| 1. Total take-off power ... | e.h.p. | 3,000 | 3,000 | 3,000 | (7,800 lb.) 3,000 |
| 2. METO power ... ... | e.h.p. | 2,480 | 2,480 | 2,730 | variable |
| 3. Cruising power assumed | e.h.p. | 1,340 | 1,340 | 1,340 | variable |
| 4. Percentage of METO power for cruise ... ... | per cent. | 54 | 54 | 49·2 | variable |
| 5. Cruising height region—operating height at start of cruise regime... | feet | 10,000 | 2,000 | 18,000 | 33,000 |
| 6. Operating height at end of cruise regime ... | feet | 10,000 | 2,000 | 20,000 | 36,000 |
| 7. Assumed average cruising fuel consumption ... | lb./hr. | 615 | 615 | 880 | 2,490 |
| 8. Assumed specific cruising fuel consumption ... | lb./e.h.p./hr. | 0·458 | 0·458 | 0·655 | 1·335 |
| 9. Cruising speed at take-off weight ... ... | m.p.h. | 212 | 110 | 264 | 343 |
| 10. Cruising speed at 85 per cent. take-off weight... | m.p.h. | 220 | 112 | 270 | 350 |
| 11. Cruising speed at 70 per cent. take-off weight... | m.p.h. | 227 | 114 | 272 | 355 |
| 12. Cruising consumption at 85 per cent. take-off weight ... ... | lb./mile | 2·80 | 5·50 | 3·26 | 7·1 |
| 13. Air miles per gallon ... | a.m.p.g. | 2·57 | 1·29 | 2·48 | 1·14 |
| 14. Theoretical still-air range at operating height, no allowances ... ... | statute miles | 1,740 | 603 | 2,140 | 922 |
| 15. Estimated take-off distance to reach 50 feet on full power at max. take-off weight ... | feet | 2,000 | Nil | 2,000 | 2,000 |

sories and drives but excluding propellers) as follows. I must emphasise that these are not precise makers' figures, but are representative for the types of engine based on average costs per horse-power for the complete power plants:—

Merlin 35 ..... £7,000 (£4.7 per h.p.)
Dart ..... £12,600 (£8.4 per h.p.)
Derwent ..... £7,000 (£4.7 per h.p.)

These prices tend to be on the high side, although one should remember that they are for complete power plants and not for bare

engines. Production experience may prove that the costs I have assumed for the turbine types are too great, particularly in relation to the figure assumed for the Dart, which has been set somewhat high to include a larger proportion of development expenses than assumed for the others.

When we examine the weights in Table XXI we see that the Dart version shows up particularly well. The comparative data can be summarised as shown in Table XXIII.

The Dart-powered aeroplane thus shows a disposable load some four per cent. greater than that of the Derwent and 27 per cent. more than that of the Merlin. The assumed volumetric capacity of the fuselage is sufficient to stow all the load which could be lifted in the Merlin Transport and the Helicopter, but, because both the Dart and the Derwent versions have an additional disposable load, they have fuel to spare even with capacity payload. The Dart has the biggest available fuel weight, followed by the Derwent.

The comparative performances in Table XXII can similarly be summarised as shown in Table XXIV.

Again, the Dart Transport shows up well. The Derwent would do better if it went higher. But for short haul operations, the climb to a still greater height, although worth while in speed, would show such a small advantage in saving of time and fuel that it would not be worth the extra weight, cost and uncertainty of increased pressurisation—that is, in the present state of the art. A compromise has thus been reached.

The fuel load and range of the helicopter have been deliberately restricted to ensure maximum performance over the short stages, for which it is most suited. The figures for the helicopter are somewhat speculative because no helicopter of such a size has yet flown. They represent as reasonable a compromise as I have been able to gauge between optimistic and pessimistic forecasts.

Taken all round, the weights and performances show up the turbine types remarkably well. And it is on such comparisons that a great deal of turbine optimism has been founded.

TABLE XXIII

| WEIGHT SUMMARY | 1. TWIN MERLIN TRANSPORT | 2. TWIN MERLIN HELICOPTER | 3. TWIN DART TRANSPORT | 4. TWIN DERWENT TRANSPORT |
|---|---|---|---|---|
| Equipped Weight | 20,200 lb. | 21,965 lb. | 18,090 lb. | 18,580 lb. |
| Disposable Load | 7,870 lb. | 6,075 lb. | 10,000 lb. | 9,550 lb. |
| Maximum Usable Fuel Load with 3,000 lb. Payload | 4,870 lb. | 3,315 lb. | 7,000 lb. | 6,550 lb. |

TABLE XXIV

| PERFORMANCE SUMMARY | 1. TWIN MERLIN TRANSPORT | 2. TWIN MERLIN HELICOPTER | 3. TWIN DART TRANSPORT | 4. TWIN DERWENT TRANSPORT |
|---|---|---|---|---|
| Mean Cruising Speed | 220 m.p.h. | 112 m.p.h. | 270 m.p.h. | 350 m.p.h. |
| Mean Height | 10,000 ft. | 2,000 ft. | 19,000 ft. | 34,500 ft. |
| Mean consumption (including allowance for engine maladjustment) | 634 lb./hr. | 634 lb./hr. | 916 lb./hr. | 2,520 lb./hr. |
| Maximum usable Fuel Load with 3,000 lb. Payload | 4,870 lb. | 3,315 lb. | 7,000 lb. | 6,550 lb. |
| Maximum duration (no allowances) | 7.7 hours | 5.25 hours | 7.64 hours | 2.60 hours |
| Theoretical Maximum Still-Air Range | 1,740 st. miles | 603 st. miles | 2,140 st. miles | 922 st. miles |

Unfortunately, it is only half the story. We now come to the application of the operational factors of allowances and reserves which are essentials, but economic millstones round the neck of Air Transport.

In discussing operating standards earlier in this Paper I detailed the philosophy behind these necessary allowances and reserves. One may note here that on comparatively short-stage operations in the U.S.A. last year, a total of 3,437 aircraft hours (representing half a million miles) were spent in non-revenue-earning traffic "stacks" — aircraft "held" awaiting landing turn. At a conservative estimate, these air traffic delays cost the U.S. airlines directly some £250,000 during 1947—leaving out of account the loss of revenue load through necessary allowances for waiting time. Such loss of payload would represent a very much higher figure—the equivalent of several millions of pounds during the year. Delays will be far more expensive for jet aircraft and one cannot emphasise too strongly, or too often, the fact that the economic success of turbine aircraft is inseparably bound up with developments in air traffic control to improve bad weather landing times while maintaining, or improving, safety.

For the purpose of this study, I have assumed that the two fixed-wing propeller types are operated under similar conditions, representative of present practice. The helicopter is, of course, another matter, and there I have assumed that reserve fuel of one hour is adequate for all conditions; the helicopter being able to put down in any reasonably open space in case of need, without diverting to an alternate. The hour's reserve over and above fuel needed to combat winds, should be adequate for instrument approaches and delays through air traffic congestion round the helicopter port.

When we turn to the Twin Derwent Transport and examine it on the same standards for allowances and fuel reserves as have to be assumed for the other Twin Transports*, we find that, on present standards, the amount of fuel required for taxi, climb, descent, diversion and stand off would occupy more than the tankage provided — a minimum payload of 3,000 lb. having been specified and the gross weight being fixed by take-off requirements. That means that both the maximum and the minimum length of stage which can be operated effectively in still air with the Twin Derwent Transport would be somewhere around 300 miles. In other words, the aeroplane is completely inflexible and its economic possibilities are made ridiculous by the fuel consumption on diversion and stand off. The aeroplane is therefore too uneconomic for the operation of regular services in present conditions—what can be achieved on a fine day in practically no wind bears no relationship to what can be done in regular service all the year round. The only hope for such a machine lies in improved air traffic control—unless it is to be operated only in a climate blessed with perpetual good weather and into relatively unfrequented airports.

Round figures of interest in this connection appear to be as follows for the fuel consumptions of transport aircraft "standing off" at 5,000 feet at 180 m.p.h.:—

Piston-engine types ... 1½ per cent. of landing weight, per hour.

Propeller-turbine types ... 2½ per cent. of landing weight, per hour.

Jet types ... 6½ per cent. of landing weight, per hour.

Thus, whereas the prop-turbine type can cope with stand off conditions at consumptions which are not too seriously increased, the jet type has four times the consumption of the piston version, which handicaps the jet aeroplane very seriously.

I have therefore assumed that before the jet can come into commercial service an improvement in methods of air traffic control will have been achieved. I have assumed that, by use of automatic landing procedures:

(i) No diversion to an alternate airport need be contemplated, and

(ii) Thirty minutes stand off at operating height is an adequate emergency reserve.

Under such conditions the Twin Derwent Transport would have a maximum block duration of 2.5 hours with 3,000 lb. of payload—equivalent to 725 miles stage length in still air at a block speed of 290 m.p.h.

If the same optimistic assumptions were applied to the Twin Dart Transport it would also have a much improved payload. This would be of the order of 3,000 lb. extra for a given stage length, or a 3½ hours longer duration. I have, however, kept to the same allowances and reserves for the Twin Dart as for the other types because such a

* Reserves for diversion of 300 still-air miles to alternate plus 1.5 hours "stack up."

reduction in standards as I have assumed to make the Twin Derwent work at all, unfortunately is completely impractical in the present status of air traffic control. The analysis of the Twin Dart Transport is therefore on standards such as it would have to observe to-day.

On the assumptions made, with the Dart operating on practical standards, but with the Derwent on "futuristic" standards, the results shown in Table XXV are achieved.

The helicopter thus scores heavily on its reserves and allowances; whereas, if the same standards were assumed throughout the Derwent would not be capable of operation. The net result is that the helicopter is capable of operating on very short stages with a fair payload, whereas for the longer ranges contemplated, the Dart and the Derwent (on their different standards) carry rather less payload than the Merlin, 40 m.p.h. faster and 100 m.p.h. faster respectively. The higher the head wind the better they show up. But we must not lose sight of the fact that the Dart is a practical proposition now and the Derwent is not (except in fine weather).

These facts are indicated more clearly in the "Hour Charts" for the four "Twin Transports," set out in Figs. 43 to 46 and in the combined curves in Fig. 47. There I have plotted block time and payload against stage length for the four aircraft, flying in still air.

This latter Figure brings out the advantage which could be enjoyed by the plain jet aircraft, on its easier operating standards. Between stage lengths of 300 and 600 statute miles in still air the jet aeroplane carries the highest payload, a fact which would be modified if all the aeroplanes were on similar standards. The helicopter does not show up well on payload, but there is not much to choose between the Dart and Merlin, the orthodox engine having a small advantage, particularly at the longer ranges. Against a head wind the turbine types will improve their position while the helicopter will be handicapped.

For a typical stage length of 400 miles the Derwent saves two hours over the helicopter in a one hour journey. It saves one hour over the Merlin and 30 minutes over the Dart.

TABLE XXV

| OPERATIONAL SUMMARY | UNITS | TWIN MERLIN TRANSPORT | TWIN MERLIN HELICOPTER | TWIN DART TRANSPORT | TWIN DERWENT TRANSPORT |
|---|---|---|---|---|---|
| Fuel allowance (taxi, climb and descent) | lb. | 645 | 271 | 1,532 | On easier standards 1,970 |
| Fuel reserve (stand off and alternate) | lb. | 1,759 | 634 | 3,450 | 1,175 (5,865 lb. on same standards as the others) |
| Shortest effective stage length (no wind), climb and descent | hrs. | 0.96 | 0.23 | 1.34 | 1.24 |
| | miles | 114 | 8 | 235 | 304 |
| Associated payload | lb. | 5,396 | 5,370 | 4,928 | 6,275 |
| Block speed (no wind) | m.p.h. | 119 | 35 | 175 | 245 |
| Maximum stage length (no wind) | hrs. | 4.74 | 3.97 | 3.44 | 2.50 |
| | miles | 878 | 408 | 773 | 725 |
| Associated payload | lb. | 3,000 | 3,000 | 3,000 | 3,000 |
| Block speed (no wind) | m.p.h. | 189 | 103 | 225 | 290 |
| Maximum stage length (60 m.p.h. head wind component) | hrs. | 4.74 | 3.97 | 3.44 | 2.50 |
| | miles | 649 | 174 | 606 | 615 |
| Associated payload | lb. | 3,000 | 3,000 | 3,000 | 3,000 |
| Block speed (60 m.p.h. head wind) | m.p.h. | 137 | 44 | 176 | 246 |

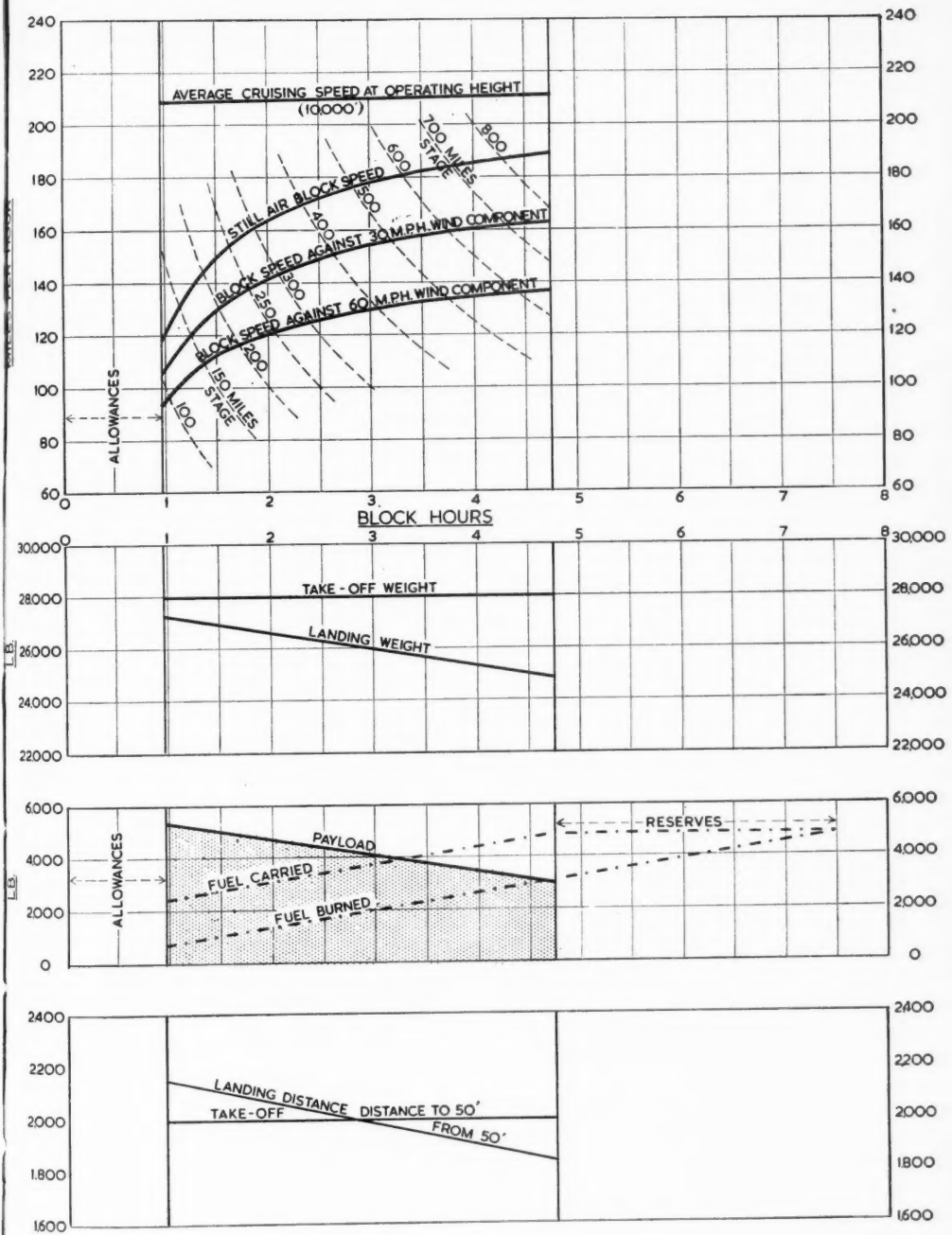


Fig. 43.
Twin Merlin Transport Hour Chart.

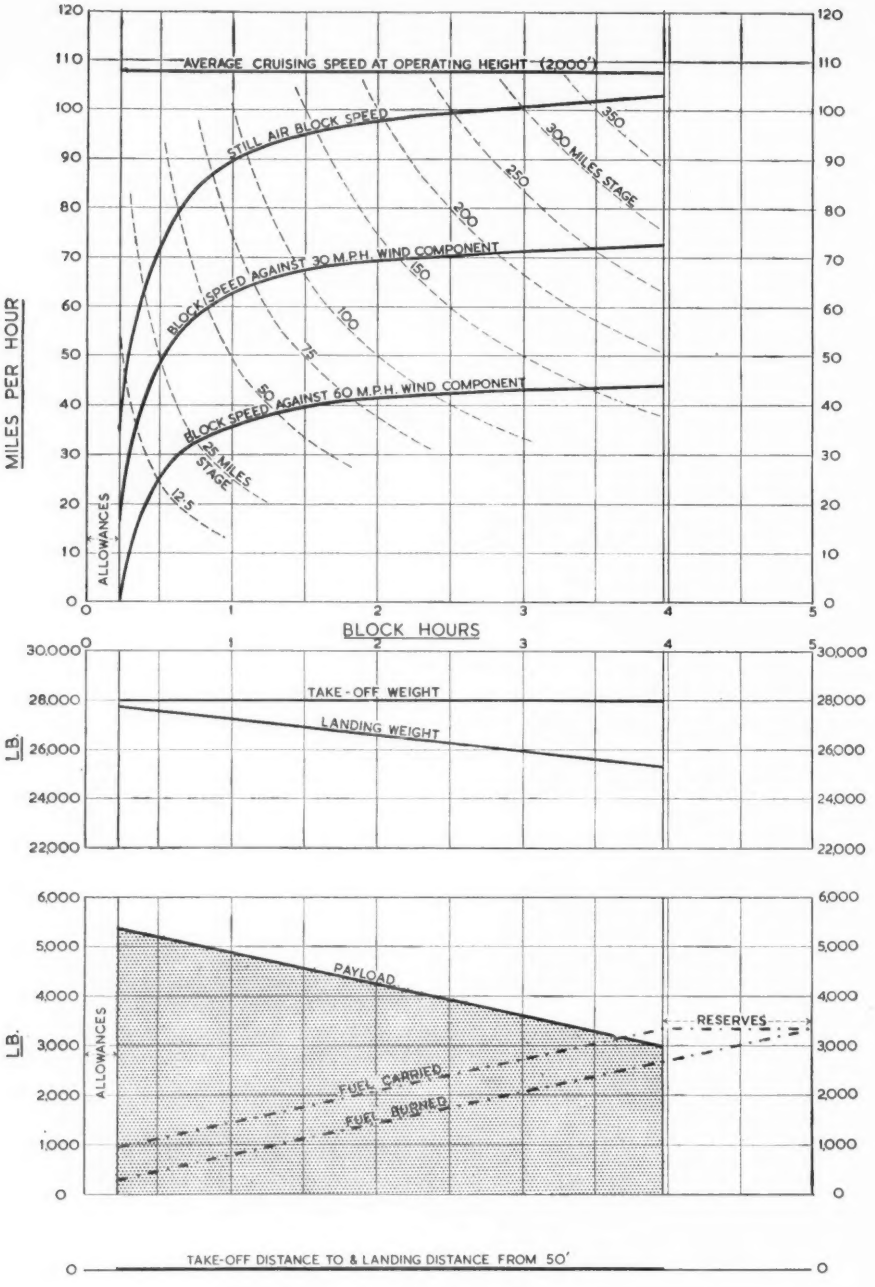


Fig. 44.
Twin Merlin Helicopter Hour Chart.

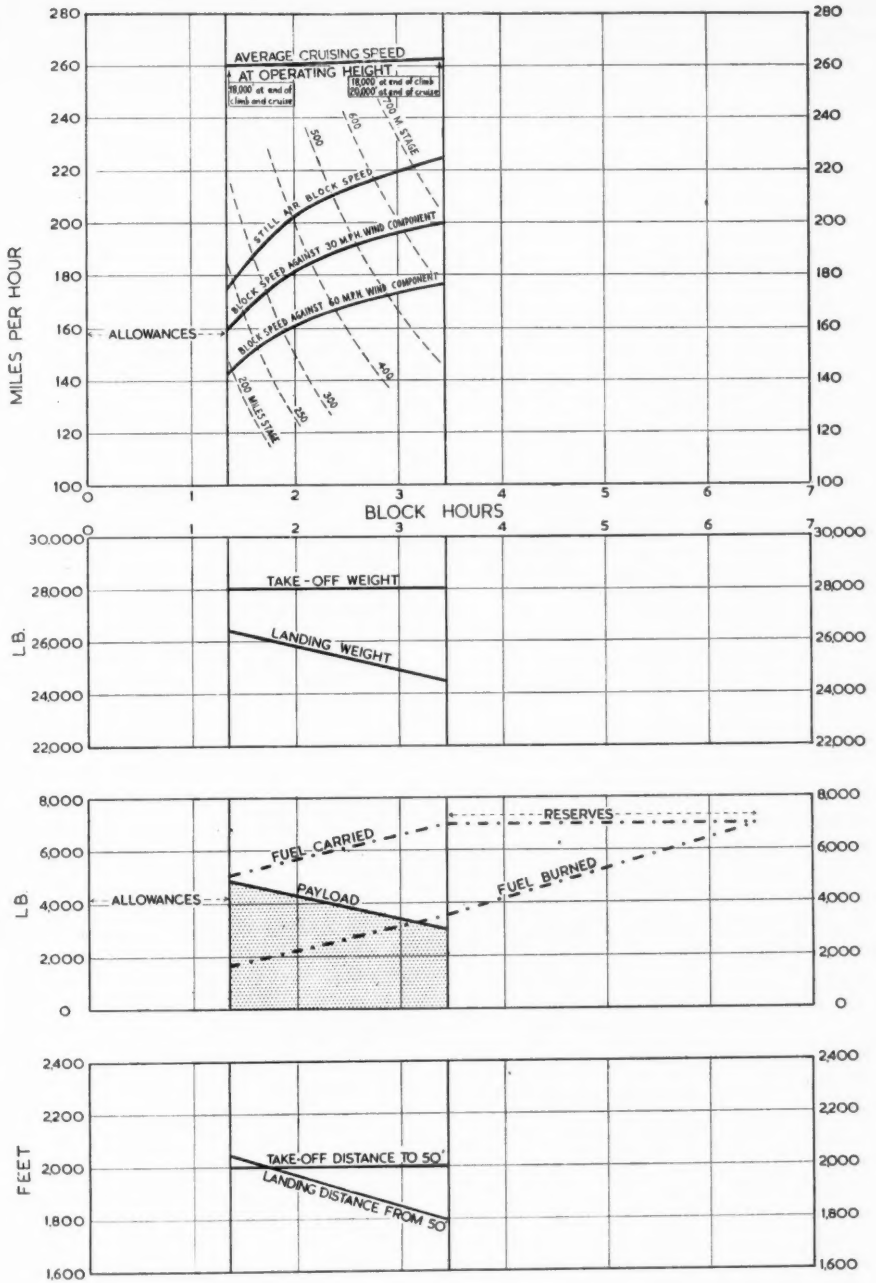


Fig. 45.

Twin Dart Transport Hour Chart.

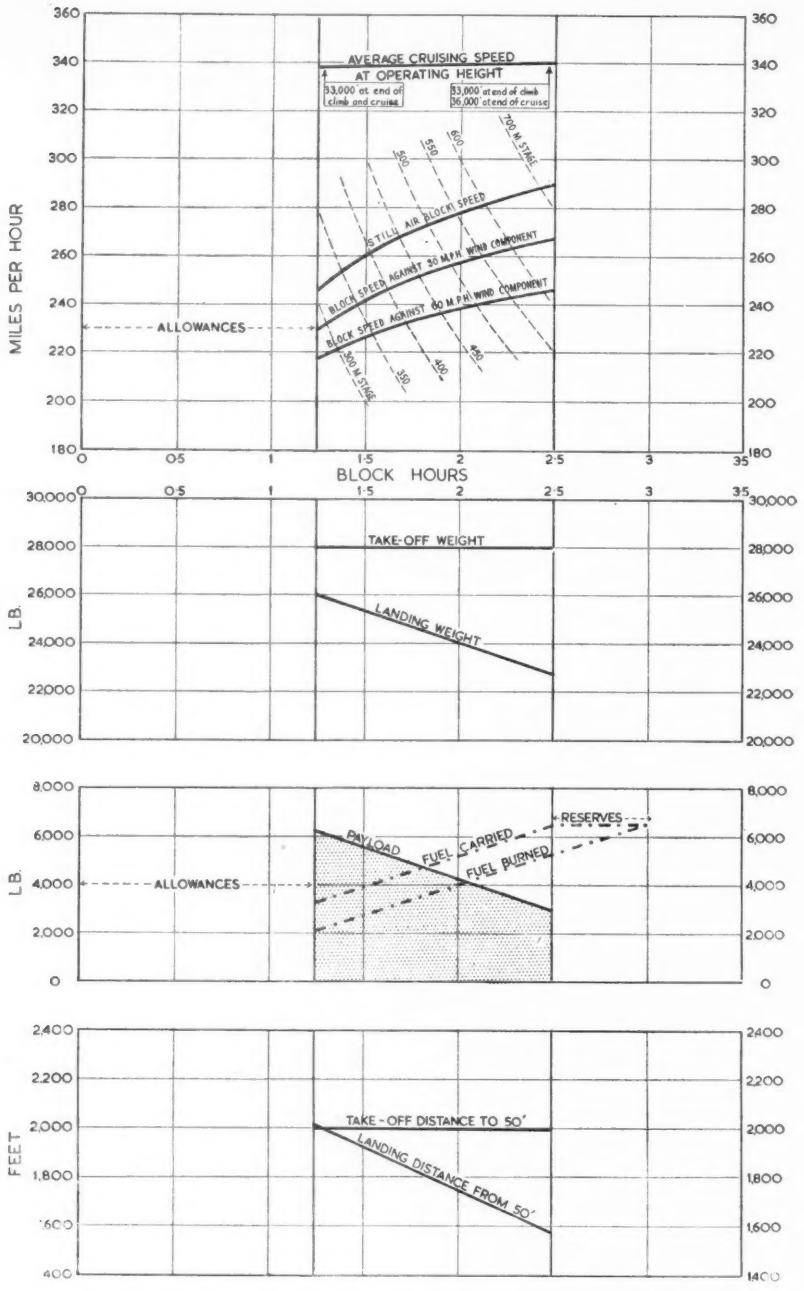


**Fig. 46.**

**Twin Derwent Transport Hour Chart.**

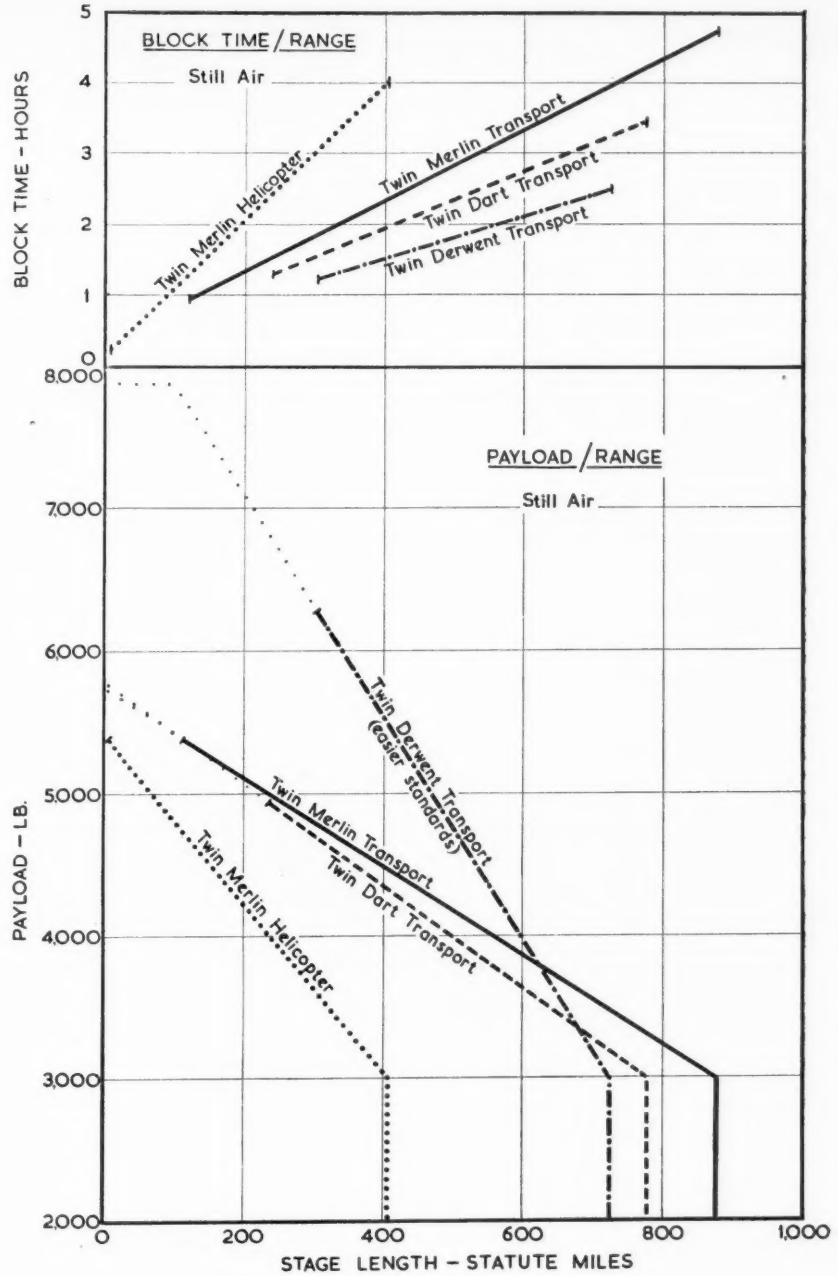


Fig. 47.

Block Time and Payload related to Stage Length—Twin Transports (in still air).

Apart from the very short ranges, at which the helicopter will be superior because of being able to operate directly into traffic centres, the Dart probably offers the most useful combination of speed, payload and range. The Derwent is somewhat restricted at both ends of its operating field but, on the standards adopted, has attractive possibilities for stage lengths of between 300 and 600 miles.

The true significance of these performances can be judged only in relation to the economics, taking into account both cost and revenue.

5.2.2. SHORT-STAGE ECONOMICS.

The price of the Twin Transports is likely to vary somewhat with the different layouts and different forms of power plant. Such evidence as is available suggests that the figures given in Table XXVI are representative of what should be capable of achievement, for a production run of 150 aircraft in each instance.

In these figures, pressurisation equipment accounts for the higher airframe costs in the Dart and Derwent versions, compared with the Merlin. The shafting and rotors account for the higher cost of the helicopter airframe, despite the absence of wing structure; the extra engine costs in the helicopter resulting from the necessary gearing and ducting.

The results are that if the cost of the Twin Merlin Transport is taken as unity, that of the Twin Derwent will be identical, that of the Twin Merlin-Helicopter 1.20, and that of the Twin Dart will be 1.21. A breakdown of the fixed annual costs, hourly cruising costs and take-off and landing costs are set out in Tables XXVII, XXVIII and XXIX.

The summarised results are as follows:—

| | T.M.T. | T.M.H. | T.D.T. | T.J.T. |
|---|---|---|---|---|
| Fixed annual costs | £44,755 | £46,745 | £50,245 | £44,485 |
| Hourly cruising costs | £23.35 | £25.28 | £23.92 | £33.50 |
| Take-off and landing costs | £57.02 | £31.37 | £58.37 | £47.78 |

In assessing these costs I have taken the same basic assumptions as for the contemporary types, except for the helicopter. I have assumed that the helicopter brings its traffic right into the city centre, with roof-top or open space termini, and that in consequence its passenger ground-handling costs will be reduced to 25 per cent. of those of fixed-wing aircraft flying from airports at city boundaries. I have assumed also that costs of outstations operations and maintenance will be reduced by 50 per cent. because, in helicopter operations, less elaborate passenger ground service would be expected and because ground transport would not be necessary at city centres.

The effect of these assumptions of simplified operations by the helicopter will be to reduce its landing costs by about 47 per cent. A reasonable assumption is that landing fees for helicopters will be no less than those for fixed wing aircraft. Although the helicopter requires a much smaller space on which to alight, that alighting area will normally be in a higher cost district—in the city centre. Helicopters flying into city centres will also require their own radio and night flying services which will tend to keep up landing costs.

TABLE XXVI

PRIME COSTS—TWIN TRANSPORTS

| Item. | T.M.T. (Merlin) | T.M.H. (Helicopter) | T.D.T. (Dart) | T.J.T. (Derwent) |
|---|---|---|---|---|
| 1. Airframe and instruments ..... | £49,000 | £60,000 | £52,000 | £52,000 |
| 2. Power plant ..... | £14,000 | £20,000 | £25,200 | £14,000 |
| 3. Propellers ..... | £3,000 | None | £3,000 | None |
| 4. Radio ..... | £4,000 | £4,000 | £4,000 | £4,000 |
| Total ..... | £70,000 | £84,000 | £84,200 | £70,000 |
| Cost per lb. of gross weight ..... | £2.5 | £3.0 | £3.01 | £2.5 |

However, some reduction of the costs of administration, both in salaries and in accommodation should be possible for helicopters because of the ability to concentrate helicopter operations at traffic centres without having to maintain separate organisations at airports—except for helicopter taxi services to meet long distance aircraft. A reasonable assumption appears to be that both administrative salaries and accommodation costs will be reduced by 20 per cent., compared with fixed-wing types, but that accommodation at out stations will remain the same. This is perhaps a little kind to the helicopter because rents in city centres are likely to be more than those at airports.

The net result on the helicopter of these assumptions will be a reduction in fixed annual costs of about four per cent., added to the reduction of 47 per cent. in landing costs.

If a utilisation of 3,000 hours is assumed, with two hours between landings, the operating costs for the four types will be:—

| | T.M.T. | T.M.H. | T.D.T. | T.J.T. |
|---|---|---|---|---|
| Per annum | £200,255 | £164,745 | £209,445 | £223,200 |
| Per hour | £66.8 | £54.9 | £69.8 | £74.5 |
| Per still air stage mile | £0.406 | £0.560 | £0.346 | £0.268 |
| Block speed (still air) m.p.h. | 164 | 98 | 202 | 278 |

These results—with three per cent. added to the costs for "dead" flying—are plotted as hourly "Cost Curves" in Fig. 48 and as comparative "U-Curves" of operating cost per revenue-ton per hour in Fig. 49. Combined with revenue, as individual "Economic Duration Curves," they are set out in Figs. 50 to 53, using the same assumptions for allowances and revenues as in the Hour Charts. The Derwent version is, therefore, running at an economic advantage because of its lighter operating standards.

Figure 48 shows that, of the four aircraft, the helicopter is the cheapest to operate per flying hour. That is entirely because of the reductions in overheads which are possible on helicopter operations—its direct flying costs being slightly higher than those of the others. For very short durations the helicopter is very expensive, as would be any of the other three. Hourly costs for the Merlin and Dart are relatively close, but those of

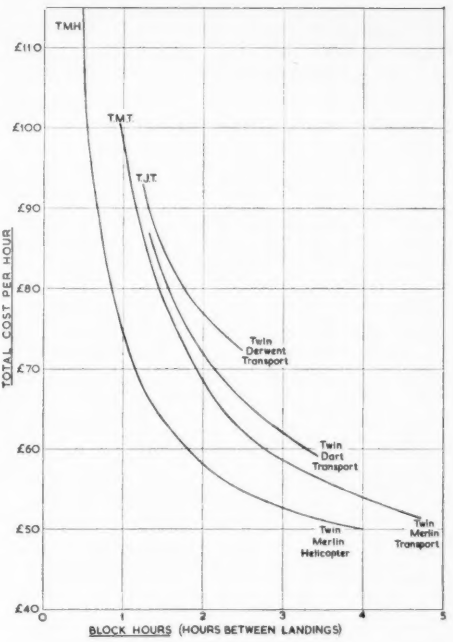


Fig. 48.

Twin Transports—Cost Curves. Total cost per hour *versus* block hours.

the Derwent are rather more because of its higher direct flying costs.

Figure 49 sets out the same figures in relation to the revenue loads, the fall in payload and the increase in block speed with duration resulting in the typical "U Curves." On these figures the helicopter is still the cheapest, with a most economic duration of about two hours. The Twin Derwent comes well down in cost at its most economic duration of 1.24 hours but rises steeply in cost with increased duration on account of its rapid fall in payload. The Dart has a most economic duration of two hours compared with 2.5 hours for the Merlin Transport, which shows itself to be the most flexible of the four types.

Figure 50 brings revenue into the picture. On the assumptions made, which are that fares would be at the same rates as for the short-range contemporary aircraft, the Twin Merlin Transport can show a profit against a 30 m.p.h. wind for durations of between 2.75 and 3.75 hours. The helicopter, on the other hand (Fig. 51), if operated at the same fares—but with 13

instead of 10 passengers per ton of payload because of the shorter distances and less baggage—can barely come out on the right side, even in still air, for durations of between 1.75 and 3 hours. Against a 30 m.p.h. wind the helicopter is bound to lose money, handicapped by its slow cruising speed.

The Dart (Fig. 52) comes out well and nets a profit between 1.8 and 3.2 hours against a 30 m.p.h. wind, while the Derwent, on its easier standards, comes out on the right side even against a 60 m.p.h. wind, over its rather restricted duration (Fig. 53).

What these durations mean in terms of stage length can be read directly from the Hour Charts. Fig. 54 takes one set of conditions and relates the four aircraft in still air. Fig. 55 does the same thing against a 30 m.p.h. wind.

These figures show that the Dart-powered aeroplane and the Merlin-powered aeroplane are practically identical in operating cost for comparable stage lengths, although the Dart flies faster and the Merlin farther. The helicopter is an economic proposition, on similar fares, only for stage lengths restricted to between 200 and 270 miles, and then only in still air. This despite fairly lenient assumptions on overheads and operating standards. The only way the helicopter can show a

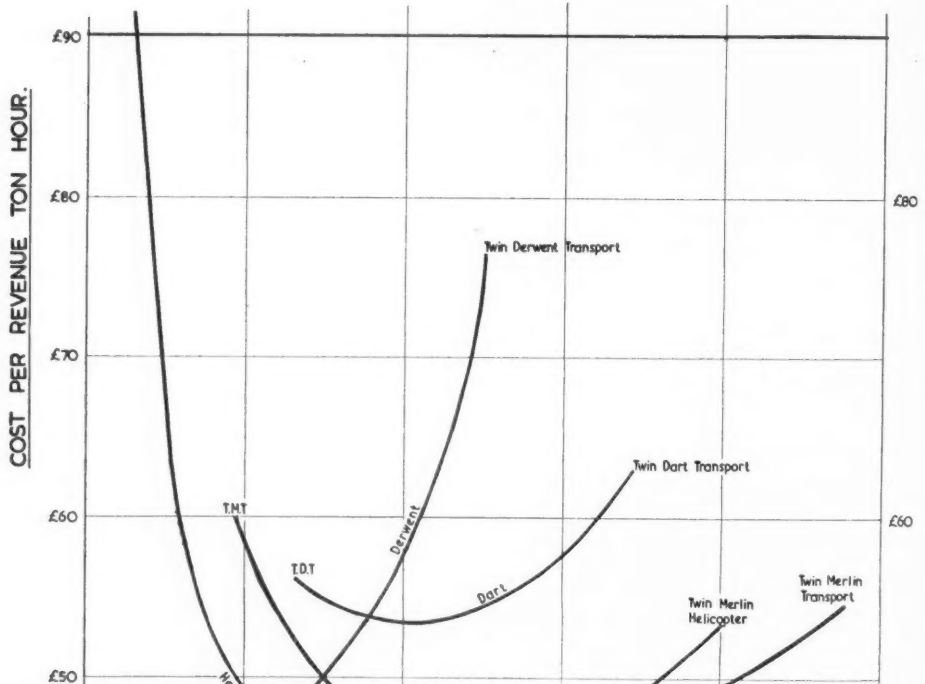


Fig. 49.

Twin Transports. Related "U"-Curves of hourly operating cost per revenue-ton of payload.

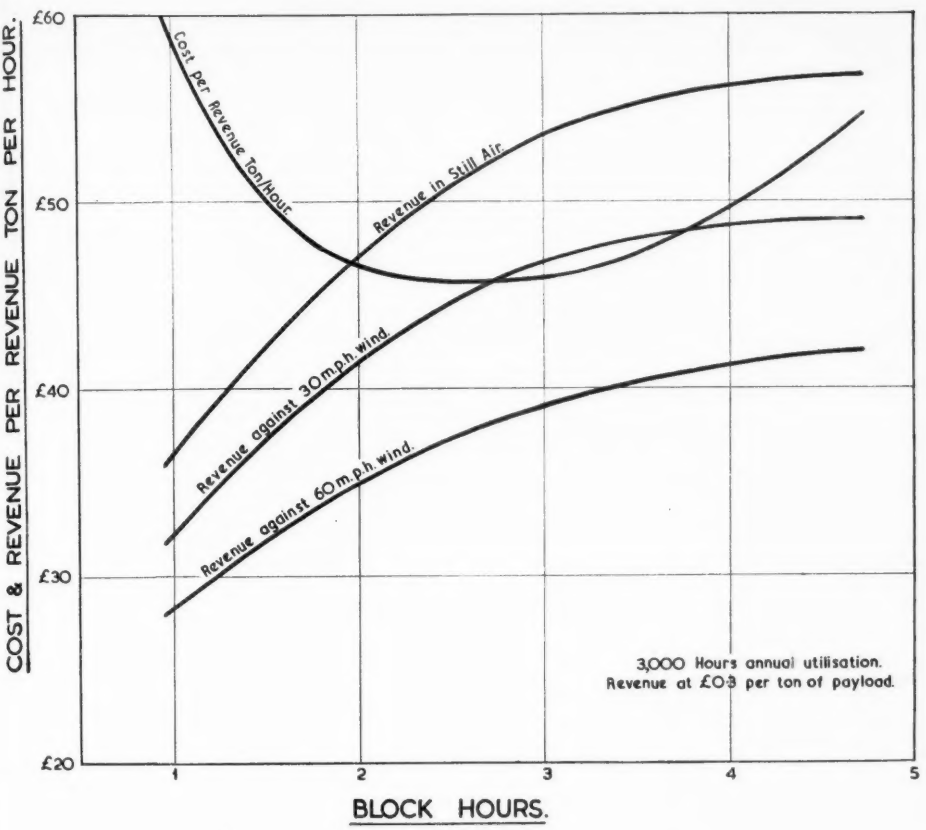


Fig. 50.
Twin Merlin Transport—Economic duration curve.

profit—on these figures—would be at passenger fares higher than the, assumed, 8d. per mile or at increased mail rates. Despite its lower hourly cost the helicopter's cost per mile is high because of the comparatively few miles it covers in an hour.

An interesting fact brought out by Figs. 54 and 55 is that both the Merlin and Dart aeroplanes will lose money on scheduled operations for stage lengths short of 270 miles, whereas the Derwent, subject to air traffic control, is profitable throughout its range. The results in still air may be summarised thus:—

T.M.T. Potential profits between 270 and 880 stage miles. Most economic distance 600 miles.

T.M.H. Potential profits between 200 and 270 stage miles. Most economic distance 225 miles.

T.D.T. Potential profits between 270 and 810 stage miles. Most economic distance 600 miles.

T.J.T. Potential profits between 300 and 725 stage miles, on easier operating standards. Most economic distance 400 miles.

Figure 55 carries this a stage farther and plots the lowest achievable operating cost over various stage lengths with the different types of power plant. Whereas the helicopter is the only answer for very short ranges—at a high cost — the Merlin is equally the only answer at the extreme ranges of the size of aircraft considered. In between, the propeller

turbine is the best answer in the immediate future, whereas the plain-jet will provide a profit at the highest speed when air traffic control makes its operation possible at all.

In Fig. 56 the profit and loss account for the various types is shown.

A comparison of the four aircraft on the basis of profit or loss per revenue ton mile brings out the interesting point that, up to a stage length of 270 miles, in still air, the helicopter is superior because of its assumed extra rate of revenue per ton of payload. From 270 to 390 miles the Twin Merlin Transport and the Twin Dart Transport are on a par, although the faster Dart will cover more revenue miles and show better annual figures for comparable payloads. From 390 to 700 miles the Dart is superior per ton of payload

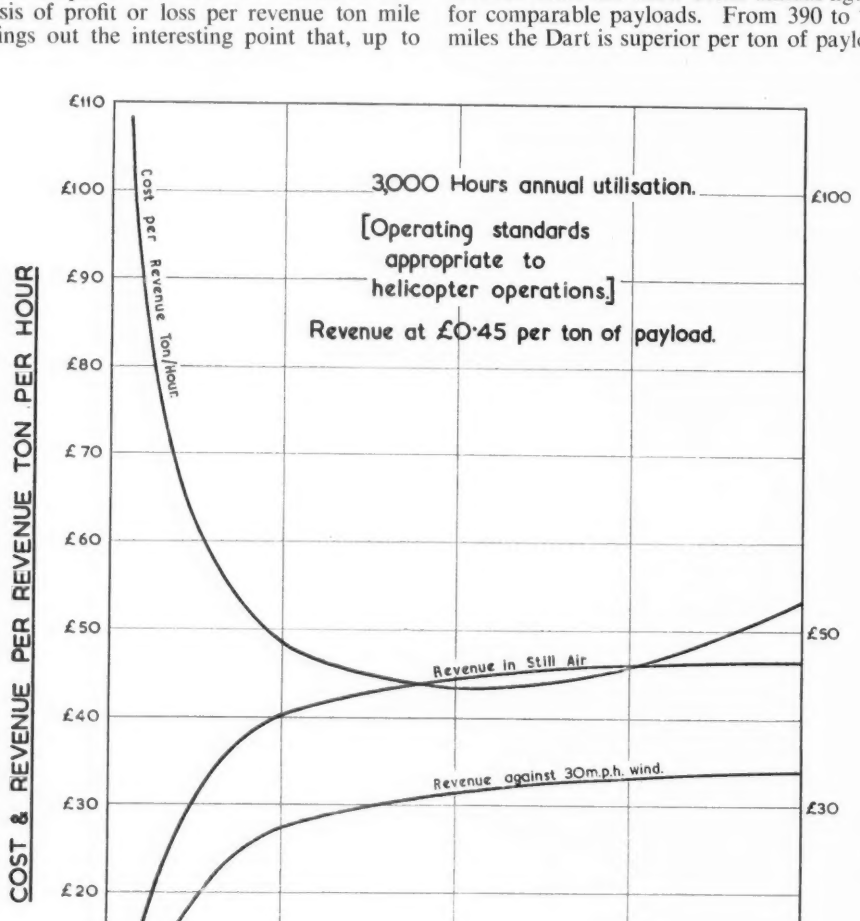


Fig. 51.
Twin Merlin Helicopter—Economic duration curve.

carried, thereafter the Twin Merlin has no competition up to its maximum still-air stage length of 880 miles.

On futuristic standards which do not offer a direct comparison with the other aircraft, the Twin Derwent Transport is an extremely profitable proposition per ton of payload carried, between stage lengths of 300 and 700 miles.

These profit and loss accounts, as set out in Fig. 56, give an indication of the varying economic efficiencies of the aircraft on the basis of cost and revenue per ton of payload. But they do not tell the whole story because they have to be related to the total amounts of payload which can be carried for the various stages in a year, to arrive at annual figures of profit or loss.

### 5.2.3. Annual Returns—Twin Transports.

So much for the background picture on the shorter range types. The implications of their characteristics can best be reviewed in relation to a typical annual operation in which not only the cost and revenue per ton mile of payload can be taken into account, but also the influence of the number of tons carried.

Take, for example, two representative operations over stage distances of 400 and 600 statute miles respectively for which the fixed wing Twin Transports have adequate performance—the 400 mile stage length being the most economic for the Twin Derwent, the 600 mile distance being the most economic for the Twin Dart and the Twin Merlin. The helicopter can obviously be ruled out for such stages and a separate study made of its most effective use.

Distances of between 400 and 600 miles approximate the average journey length made by an air passenger and represent the approximate distances apart between such important traffic centres as London and Copenhagen, London and Marseilles, and London and Berlin for the longer stage, or between London and Edinburgh, London and Glasgow, Sydney and Melbourne, and Toronto and Montreal, for the shorter stages.

The results of the analyses are set out in Tables XXX and XXXI, based on the assumptions of 3,000 hours annual utilisation, a 65 per cent. passenger load factor (70 per cent. overall load factor), revenue at 8d. per passenger mile (£0.3 per ton mile of combined payload) and costs at the levels

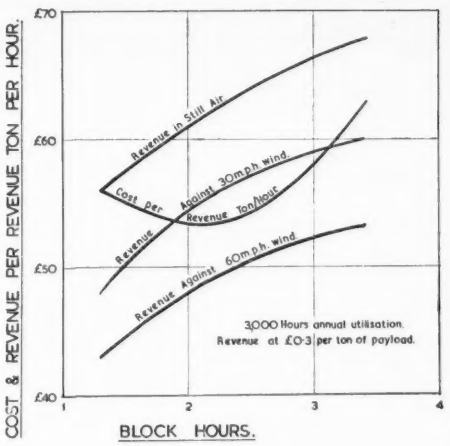


Fig. 52.
Twin Dart Transport—Economic duration curve.

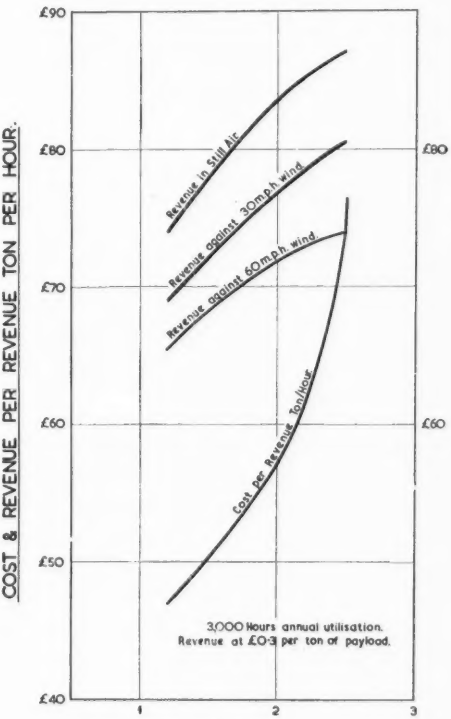


Fig. 53.
Twin Jet Transport—Economic duration curve.
(Easier operating standards adopted compared with other Twin Transports.)

assumed for the contemporary aircraft. For assistance in working out the laborious calculations necessary to arrive at conclusions on the economics on these and the other aircraft surveyed I am much indebted to my colleague Mr. J. G. Simms, O.B.E., M.A.

Over the stage length of 600 miles the Twin Derwent Transport shows up best, at its easier operating standards, with an estimated annual profit of £25,200 (ten per cent. of the turnover), carrying an annual total of 1,400 tons of payload. Although it takes less payload per trip its speed enables it to put in some 30 per cent. more trips in the year, compared with the Twin Dart Transport, and some 40 per cent. more trips compared with the Twin Merlin Transport, even allowing for the higher head winds it will meet at its greater operating height.

The Twin Merlin and the Twin Dart show annual profits of £14,500 and £5,500 respectively carrying payloads of 1,050 and 1,080 tons. Over this 600 mile stage length the Dart shows the least good results, because its payload falls below that of the Merlin as a result of its higher consumption on diversion and stand off and because it has not enough additional speed to make up for the loss in payload. Even so the Twin Dart puts in some 20 per cent. more trips than the Merlin and saves about 34 minutes per journey. A small improvement in air traffic control would make the Dart a more attractive proposition than the Merlin for this stage length.

Turning to the shorter stage of 400 miles, the assumed easier operation standards of the Derwent enable it to achieve the extraordinarily high profit of £124,500 (33 per cent. of the turnover), carrying a total payload of 2,070 tons. This is an excellent example of

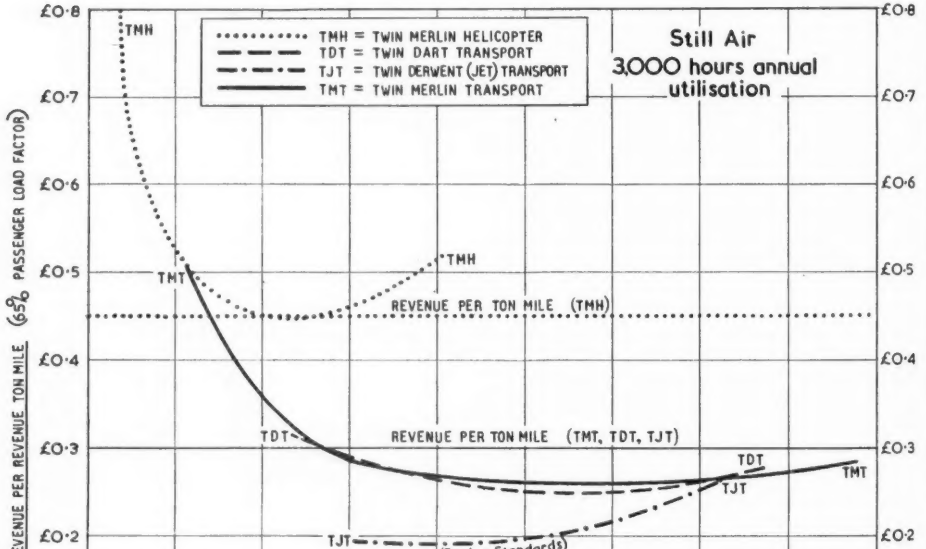


Fig. 54.

Comparative Economic Stage Length Curves—Twin Transports (in still air).

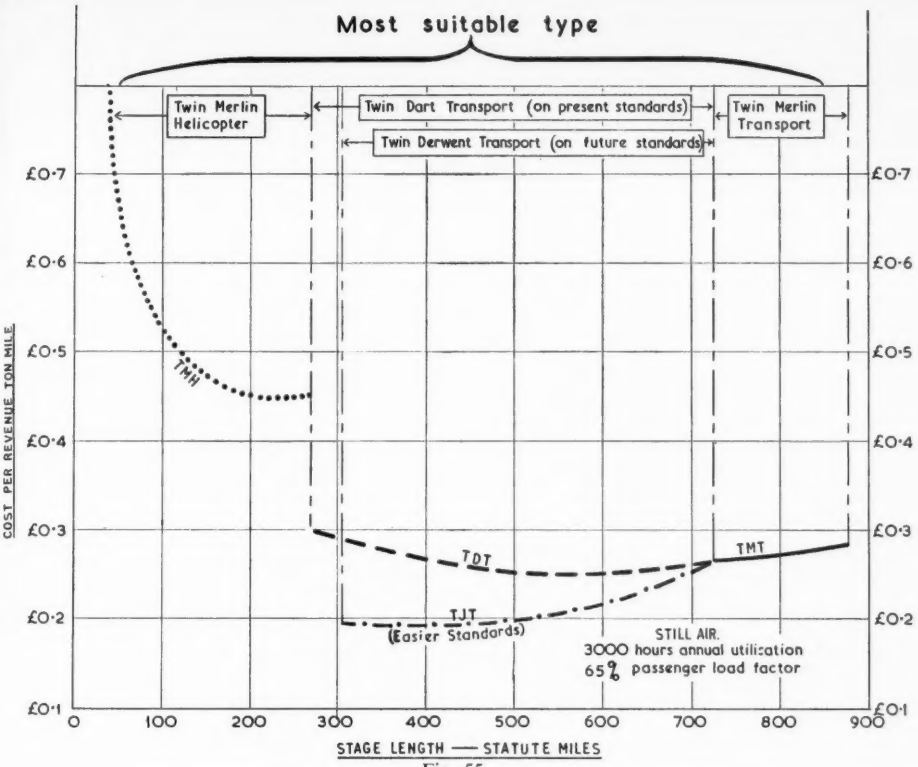


Fig. 55.

Lowest achievable operating cost per revenue ton of payload—Twin Transports.
(Indicating type of aircraft which will achieve lowest costs at various stage lengths in still air.)

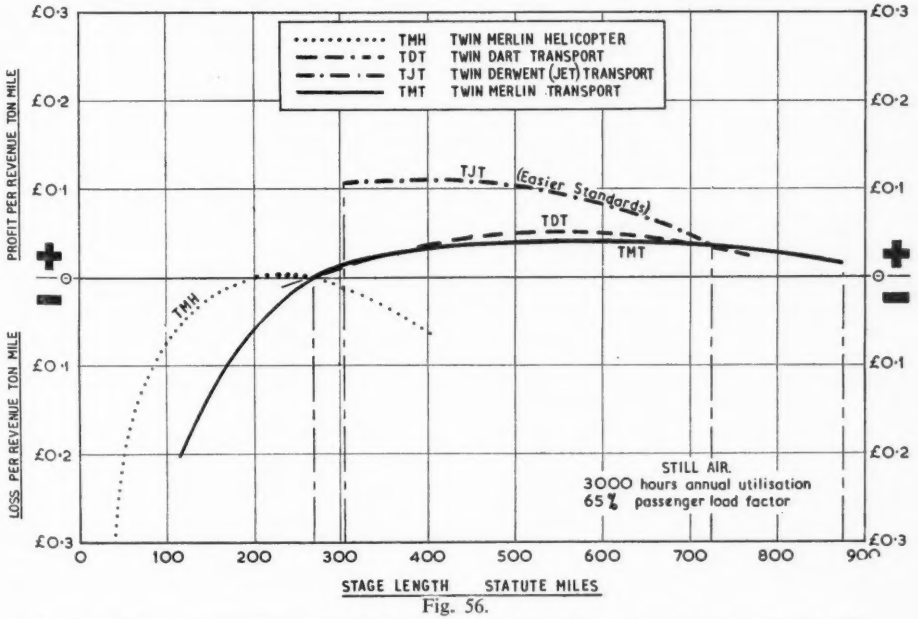


Fig. 56.

Profit and Loss—Twin Transports (Indicating potential profit or loss per revenue ton mile over various stage lengths in still air.)

## TABLE XXX

## TWIN TRANSPORTS—
## ANNUAL OPERATION OVER 600-MILE STAGE
## (3,000 HOURS EFFECTIVE UTILISATION)

| | Units | Twin Merlin Transport | Twin Dart Transport | Twin Jet Transport |
|---|---|---|---|---|
| Block speed versus 10 m.p.h. wind ... ... ... | m.p.h. | 175 | 210 | (easier standards) 276 |
| Average block time single trip ... ... ... | hours | 3·43 | 2·86 | 2·175 |
| Annual revenue—miles flown ... ... ... ... | statute miles | 515,000 | 630,000 | 828,000 |
| Operational cost per hour (3 per cent. dead flying allowed for) ... ... ... ... ... ... | £ | £57 | £63 | £75 |
| Operational cost per annum ... ... ... ... | £ | £171,000 | £189,000 | £225,000 |
| 85 per cent. worst season wind ... ... ... | m.p.h. | 30 | 37 | 54 |
| Speed at 85 per cent. worst season wind ... ... | m.p.h. | 160 | 190·5 | 250 |
| Block time at 85 per cent. worst season wind ... ... | hours | 3·75 | 3·15 | 2·4 |
| Booking payload ... ... ... ... ... | lb. | 3,850 | 3,300 | 3,250 |
| 70 per cent. booking payload ... ... ... ... | tons | 1·202 | 1·03 | 1·015 |
| Operational revenue per annum at £0·3 per R.T.M. ... | £ | £185,500 | £194,500 | £250,200 |
| Payload carried per annum ... ... ... ... | tons | 1,051 | 1,079 | 1,400 |
| Annual profit ... ... ... ... ... ... | £ | £14,500 | £5,500 | £25,200 |
| Profit per mile ... ... ... ... ... ... | pence | 6·76d. | 2·095d. | 7·3d. |
| Profit per hour ... ... ... ... ... ... | £ | £4·825 | £1·83 | £8·4 |
| Profit per ton of payload ... ... ... ... | £ | £13·9 | £5·095 | £18 |

the extent to which the costs of air transport could be reduced, and hence the fares brought close to those of surface transport, if a solution can be found for problems of air traffic control. The Twin Derwent Transport achieves these results from its higher speed, combined with the higher payload which it can carry over short stages, because it is not penalised by crippling fuel reserves.

The Dart comes out better than the Merlin on this stage and returns a profit of £15,000 on the carriage of 1,900 tons of payload, compared with the Merlin's profit of £9,600 on the carriage of 1,650 tons of payload. These profits represent 6.5 and 4.85 per cent. of the turnover and would be a good deal higher on similar standards to those assumed for the Derwent—a comparison which is dealt with in the next section. For a 400-mile stage although the Dart's payload is little lower than the Merlin's, the Dart's additional speed enables it to make 20 per cent. more journeys in the year and rake in more profits.

On present standards, therefore, the Twin Dart Transport is superior for the 400 mile stage length, whereas the Twin Merlin Transport earns more annual profit over the

## TABLE XXXI

## TWIN TRANSPORTS—
## ANNUAL OPERATION OVER 400-MILE STAGE
## (3,000 HOURS EFFECTIVE UTILISATION)

| | Units | Twin Merlin Transport | Twin Dart Transport | Twin Jet Transport |
|---|---|---|---|---|
| Block speed versus 10 m.p.h. wind ... ... ... | m.p.h. | 164 | 197 | (easier standards) 256 |
| Average block time single trip ... ... ... | hours | 2·44 | 2·03 | 1·56 |
| Annual revenue—miles flown ... ... ... ... | statute miles | 492,000 | 591,000 | 768,000 |
| Operational cost per hour (3 per cent. dead flying allowed for) ... ... ... ... ... ... | £ | £62·75 | £71·5 | £83·5 |
| Operational cost per annum ... ... ... ... | £ | £188,200 | £214,500 | £250,500 |
| 85 per cent. worst season wind ... ... ... | m.p.h. | 30 | 37 | 54 |
| Speed at 85 per cent. worst season wind ... ... | m.p.h. | 151 | 180 | 235 |
| Block time at 85 per cent. worst season wind ... | hours | 2·65 | 2·22 | 1·7 |
| Booking payload ... ... ... ... ... | lb. | 4,300 | 4,150 | 5,100 |
| 70 per cent. booking payload ... ... ... ... | tons | 1·34 | 1·295 | 1·592 |
| Operational revenue per annum at £0·3 per R.T.M. ... | £ | £197,800 | £229,500 | £375,000 |
| Payload carried per annum ... ... ... ... | tons | 1·648 | 1·194 | 3·070 |
| Annual profit ... ... ... ... ... ... | £ | £9,600 | £15,000 | £124,500 |
| Profit per mile ... ... ... ... ... ... | pence | 4·78d. | 6·09d. | 38·95d. |
| Profit per hour ... ... ... ... ... ... | £ | £3·2 | £5 | £41·5 |
| Profit per ton of payload ... ... ... ... | £ | £5·82 | £7·84 | £40·55 |

600 mile stage. On present standards the Twin Derwent Transport could not operate at all. The propeller-turbine aeroplane carries more payload in the year than does the piston-engine aeroplane for both stage lengths.

If problems of air traffic control can be reduced to eliminate diversions and reduce fuel reserves needed for "stacking," then the Twin Derwent Transport would come into the competition and, for stage lengths between 300 and 700 miles, would offer the most attractive services, as a result of its high speed, gained while operating economically.

A survey of this sort underlines the promise inherent in the jet for commercial operations. On the different assumptions made the most worthwhile aeroplane of the three is the Twin Derwent Transport, remembering always that its operational performance is based on easier standards than the others, which themselves would be improved were they on the same assumptions.

The economic advantage of the jet type lies very largely in its increased earning capacity for a given utilisation. It flies 50 per cent. more miles in the year than does the equivalent piston aeroplane and can

therefore perform more revenue journeys. So long as it is being flown over an economic stage, it can make a profit or, better still, reduce fares materially.

Within its limitations on range, therefore, the jet type shows up well. The one snag—and a dominant factor—is that, on present control standards, the small jet transport *cannot be operated commercially at all* so that no advantage can be taken, as yet, of its high promise.

### 5.2.4. The effect of operating standards.

The required degree of improvement in air traffic control to make jet aircraft commercially feasible is an interesting subject for speculation.

In the studies of the Twin Transports I have assumed that the two extremes for short haul services are as follows:—

(*a*) *Present Operating Standards.*—Diversion allowance: 300 miles. Stand off: 1.5 hours. Fuel reserves required for Twin Derwent Transport: 5,865 lb.

(*b*) *"Futuristic" Operating Standards.*—Diversion allowance: Nil. Stand off: 0.5 hours. Fuel reserves required for Twin Derwent Transport: 1,175 lb.

By contrast, the Twin Merlin Transport would require fuel reserves of 1,759 lb. on present operating standards. But the allowances for taxi, climb and descent are so much less for the standard piston engines than for the jet that, even on present standards, the allowances and reserves for the Twin Merlin Transport would total only 2,404 lb., while those for the Twin Derwent on futuristic standards would amount to 3,145 lb. So, even on the advanced standards, the jet is worse off.

On diversion to an alternate airport there are no two ways about it—either you divert or you don't. Until all-weather landings are possible on all occasions on which operations are undertaken, fuel reserves for diversion must be carried. Jets will suffer a serious handicap until all diversion reserves can be eliminated without sacrifice of regularity.

The stand-off allowance can be dealt with more easily. Assuming no diversion but the full 1.5 hours stand off, the Twin Derwent Transport will consume 3,525 lb. of fuel during "stacking." From this we can construct a table as follows—ignoring here the small effect of change of flying weight and assuming extra tanks:—

| | Twin Derwent Transport Fuel Allowances and Reserves | Booking Payload |
|---|---|---|
| A. On present standards ... | 7,835 lb. | 1,310 lb. |
| B. No diversion: 1.5 hours stand off | 5,495 lb. | 3,650 lb. |
| C. No diversion: 1.0 hours stand off | 4,320 lb. | 4,825 lb. |
| D. No diversion: 0.5 hours stand off | 3,145 lb. | 6,000 lb. |

On present standards, therefore, for the "minimum" stage length of 300 miles accomplished during climb and descent, the load-factored payload would be 920 lb. (four passengers plus 120 lb. of mail and freight). This revenue load would rise to 4,200 lb. (21 passengers) on the "futuristic" standards, assuming air traffic control developed to the extent at which half an hour's reserve fuel would be sufficient for all conditions, at the necessary commercial regularity.

When we turn to the annual accounts, on the assumed "futuristic" standards of only 0.5 hours stand off and no diversion, the Twin Derwent Transport has a potential annual profit of £132,000. On the present and on the more advanced standards the following results would be gained:—

| | Twin Derwent Transport (300 mile stage) Annual Profit | Annual Loss |
|---|---|---|
| A. On present standards | ——— | £187,000 |
| B. No diversion: 1.5 hours stand off | ——— | £28,800 |
| C. No diversion: 1.0 hours stand off | £52,000 | ——— |
| D. No diversion: 0.5 hours stand off | £132,000 | ——— |

In a word, at the governing weights the Twin Derwent Transport would be limited to very short ranges on present standards and would lose a substantial sum on them. When diversions can be eliminated, but a stand off reserve of 1.5 hours is still required, then the Twin Derwent would still lose money. With fuel reserves for one hour stand off, or less, it would gain—at present fares.

The result of adopting the most advanced standards for the propeller-driven Twin Transports would be to increase the payload at no extra cost—thus increasing the profits substantially. The comparison is then as follows for the 300 mile stage length:—

| 300 Mile Stage | Twin Merlin Transport | Twin Dart Transport | Twin Derwent Transport |
|---|---|---|---|
| A. Present standards ... | Annual profit £1,600 | Annual loss £1,000 | Annual loss £187,000 |
| B. No diversion: 1.5 hours stand off ... | Annual profit £78,100 | Annual profit £88,500 | Annual loss £28,800 |
| C. No diversion: 1.0 hours stand off ... | Annual profit £90,800 | Annual profit £119,000 | Annual profit £52,000 |
| D. Futuristic standards ... | Annual profit £104,800 | Annual profit £148,000 | Annual profit £132,000 |

All this means that the short range jet transport is entirely dependent on developments in air traffic control for economic success at present fares, whereas the propeller-turbine aeroplane is more flexible operationally, and could almost break even over uneconomically short stages even on present standards for which the Twin Merlin is best suited. When air traffic control has been developed, the jet will offer almost equal financial rewards at considerably higher speeds than the propeller-turbine—and will have greater passenger attractions. In other words progression will have to be by way of the propeller-turbine to the jet.

What do these assumptions of improved standards involve?

Elimination of any reserves for diversion means that landings would have to be guaranteed at the intended terminal, without peradventure, the maximum delay being a stand off of up to, say, 1.5 hours. Such an advance may not prove to be too difficult in Summer. It will be difficult all the year round until automatic landing is possible. To eliminate diversions and, at the same time, cut down stand off reserves to no more than half an hour is shooting very high indeed. In my view entirely automatic approach control, let down and landing will be necessary. Five years' hard work will probably be necessary on ground aids before the jet aeroplane can really come into its own. There is no time to be lost. For, like the perambulatory Campbells, the jets are coming.

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A number of general conclusions can now be drawn from this survey of shorter range transport aircraft.

*First*, because of its high consumptions at low speeds and heights, the plain jet aeroplane cannot be a commercial proposition in the present state of air traffic control—except perhaps in a few good weather areas of low traffic density.

*Second*, the plain jet aeroplane to be effective in present conditions would have to be built much bigger than an equivalent propeller type, in order to stow the extra fuel required for a particular stage. The result would be more weight, more power to maintain take-off requirements and hence higher costs and less economy.

*Third*, given improved air traffic control all types of aeroplane will become cheaper to operate but the greatest benefit will be enjoyed by the jet. Once the diversion and "stack up" problem is eliminated the plain jet, by virtue of its speed, can become almost as cheap to operate as propeller-powered aircraft at much higher speeds, although somewhat restricted in range.

*Fourth*, in the meantime the propeller turbine offers advantages of speed over the orthodox engine at approximately the same cost per revenue mile, although for a slightly narrower band of effective ranges, being limited in economy over very short stages or over the longer stages of which the piston engine is capable.

*Fifth*, in general, the propeller turbine-powered aeroplane will have to be somewhat bigger than the piston-powered aeroplane to achieve the same flexibility of performance. Granted a larger aeroplane, then the propeller turbine can be at least as economic, at higher speed.

*Sixth*, the helicopter is more expensive to operate per revenue ton mile than any equivalent fixed-wing aeroplane and because of its low speed will be much more influenced by surface winds. Nevertheless the helicopter is the only possible form of air transport for short inter-city stages. For short stages higher rates may be contemplated to make the helicopter a commercial proposition.

One thing stands out above all others. It is that the plain jet aeroplane offers immense economic possibilities for the moderate ranges surveyed. At present they must remain only as possibilities because the jet is strangled at birth by limitations imposed by air traffic control.

First in order of priority must be, therefore, improvements in control methods so as to make possible a high frequency of landings in bad weather—safely. I have already said

that, in my view, the most promising solution lies in automatic "let down," approach and landing, using the automatic pilot coupled to the blind landing beam. There is no quick answer and much research and experiment remains to be done.

The need for the work is plain. The economic advantages are manifest.

In the meantime, the propeller-turbine has much to offer. The experience which the United Kingdom is now beginning to acquire with such pioneering types of propeller-turbine transport aeroplane as the Dart-engined Vickers-Armstrongs Viscount and the Mamba-engined Armstrong Whitworth Apollo will be of the utmost importance for the future. The Derwent-powered Canadian-Avro C-102 and the research Nene-Viking will similarly build up experience on the plain jet within the next short while. All of them will concentrate attention on the problems of air traffic control.

## 5.3. COMPARATIVE TRANSPORT POSSIBILITIES.

### 5.3.1. INCOME VALUES AND TRANSPORT COSTS.

We see from all this that aeroplanes with turbine power plants can save a good deal of time, compared with other types, for specific ranges. Speed does not always cost more and will often compensate for extra costs by an enhanced revenue earning potential. Air travel is at present more expensive than surface transport, although air travel over appropriate stages can result in a material saving of time over any other means of transport.

How much is this time saved worth? Can extra speed be afforded and if so, how much extra speed is worth while?

There are many intangibles in such a query. I have attempted to discover a partial answer to the question by an analysis of incomes. From them some judgment may be formed of how much the saving of a working hour is worth.

In the United Kingdom in 1948, a total of approximately 29 million persons had incomes of more than £150 a year. The total incomes of these 29 million people amounted to £7,845 million. That is an average annual income of £270 a head of the earning, or income drawing, population—about 1s. 4d. an earning hour.

As the average cost of air transport is about £3 per passenger seat per hour it is obvious that persons earning 1s. 4d. an hour cannot normally afford to pay the earnings of nearly two weeks work for an hour of flying—unless it saves them two weeks thereby as, in some parts of the World, air communications do. They might pay that amount for an occasional jaunt, but neither they nor their employers would pay £3 to save an hour if an hour of their time was worth but 1s. 4d. Furthermore income tax has to be deducted so that the "net hour" is worth still less.

On the other hand if a journey were really necessary and if one form of transport saved an hour over another form of transport at a cost of only 1s. 4d. extra, then that more expensive form of transport would be worth while as a business proposition—the working hour being worth 1s. 4d.

Leaving aside the intangible advantages of convenience and comfort afforded by Air Transport we can reach the conclusion that the absolute cost of Air Transport per hour is no guide, except in relation to the amount of time it can save as compared with other forms of transport. The chief thing which Air Transport has to sell is—time.

Analysing the income figures further, we find that there were 1,740,000 people in the United Kingdom in 1948 who earned between £500 and £1,000 a year. Their total incomes amounted to £1,190 million. That is an average of £685 a head; or about 6s. 8d. a working hour.

There were 495,000 people with incomes from £1,000 to £2,000 a year. They earned a total of £670 million in 1948; an average of £1,350 a year or 13s. 4d. a working hour.

The 157,000 people who have incomes from £2,000 to £10,000 a year earned—or at least acquired—£547 million in the year—an average of £3,480 each or £1 15s. 0d. a working hour.

Then there are 8,000 people with incomes of more than £10,000 a year. These 8,000 amass £148 million in a year—before Sir Stafford gets at it. Their average income is thus £18,500. This works out at £9 5s. 0d. "per working hour"—or £1 13s. 2d. an hour after income tax is deducted.

So that, all in all, there were about 660,000 wage earners (2.28 per cent. of the total) with incomes of more than £1,000 a year. The average earnings per working hour of these 660,000 is just over 20 shillings.

What this suggests to me is that, if the average man of this half million odd can save

an hour by flying it is worth at least £1 to him; more rather than less because of extra work which can be crowded into a shorter time if an hour is saved. Therefore, as an example, the advantage of the helicopter in achieving a high block speed over short range is worth £1 higher fare per hour saved. In other words, the economic scale is that it is worth spending £1 to save one hour—for 2.28 per cent. of the earning population. Improvements in economy will bring Air Transport within the reach of a much wider public—for pleasure as well as for business.

5.3.2. SPEED VERSUS COST.

Applying this in practice to a bus, a train, a helicopter and an aeroplane, typical figures can be set down as shown in Table XXXII.

Figure 57 shows these facts in pictorial form, while Fig. 58 and 59 set them out graphically. Up to a distance of 215 miles between city centres the fastest means of transport, on the figures taken, is the helicopter. For distances of more than 215 miles between city centres the aeroplane is the fastest.

An interesting point, shown in Fig. 58, is that the aeroplane is the slowest means of inter-city transport up to a distance of 50 miles, because of the terminal delays. The aeroplane and the bus achieve equal journey times for a 50 mile distance, although the aeroplane is five times more expensive. The aeroplane is slower than the train up to distances of 90 miles between city centres where they take equal times, but the aeroplane costs twice as much.

Figure 59 illustrates journey cost in terms of duration of trip. For all journeys, the bus is the cheapest means of transport—both in cost per mile and in cost per hour. The train is always cheaper per mile than the aeroplane, but for a journey time of two hours the train and the aeroplane cost an equal amount. Unfortunately for the aeroplane, as a result of terminal delays, it covers only 40 miles in a two-hour journey between city centres, compared with the train's 82 miles. The aeroplane is therefore not in the running for such a duration of journey time.

The helicopter and the aeroplane have, on the assumptions made, the same cost per

TABLE XXXII

| | Bus | Train | Helicopter | Aeroplane (Ambassador) |
|---|---|---|---|---|
| Typical en route cruising speed at operating height | 25 m.p.h. | 45 m.p.h. | 112 m.p.h. | 270 m.p.h. |
| Assumptions | 30 minutes stop every 4 hours. No other delays. | 5 mins. delay each end. | 10 m.p.h. head wind. Rooftop termini. 5 mins. delay each end. | 10 m.p.h. head wind. 40 mins. delay each end. |
| Fare: | 1.5 pence per passenger mile. | 4 pence per passenger mile (first class). | 8 pence per passenger mile. | 8 pence per pasenger mile. |
| 25 miles stage City centre to City centre. | 1.0 hrs. £0.16 cost | 0.72 hrs. £0.42 cost | 0.6 hrs. £0.83 cost | 1.93 hrs. £0.83 cost |
| 50 miles stage City centre to City centre. | 2.0 hrs. £0.31 cost | 1.28 hrs. £0.83 cost | 0.86 hrs. £1.67 cost | 2.03 hrs. £1.67 cost |
| 100 miles stage City centre to City centre. | 4.0 hrs. £0.63 cost | 2.38 hrs. £1.67 cost | 1.4 hrs. £3.33 cost | 2.18 hrs. £3.33 cost |
| 200 miles stage City centre to City centre. | 8.5 hrs. £1.25 cost | 4.62 hrs. £3.33 cost | 2.4 hrs. £6.67 cost | 2.53 hrs. £6.67 cost |
| 500 miles stage City centre to City centre. | 21.5 hrs. £3.13 cost | 11.28 hrs. £8.33 cost | 5.82 hrs. £16.67 cost | 3.83 hrs. £16.67 cost |
| 1,000 miles stage City centre to City centre. | 44.5 hrs. £6.25 cost | 22.38 hrs. £16.58 cost | 11.33 hrs. £33.33 cost | 5.83 hrs. £33.33 cost |

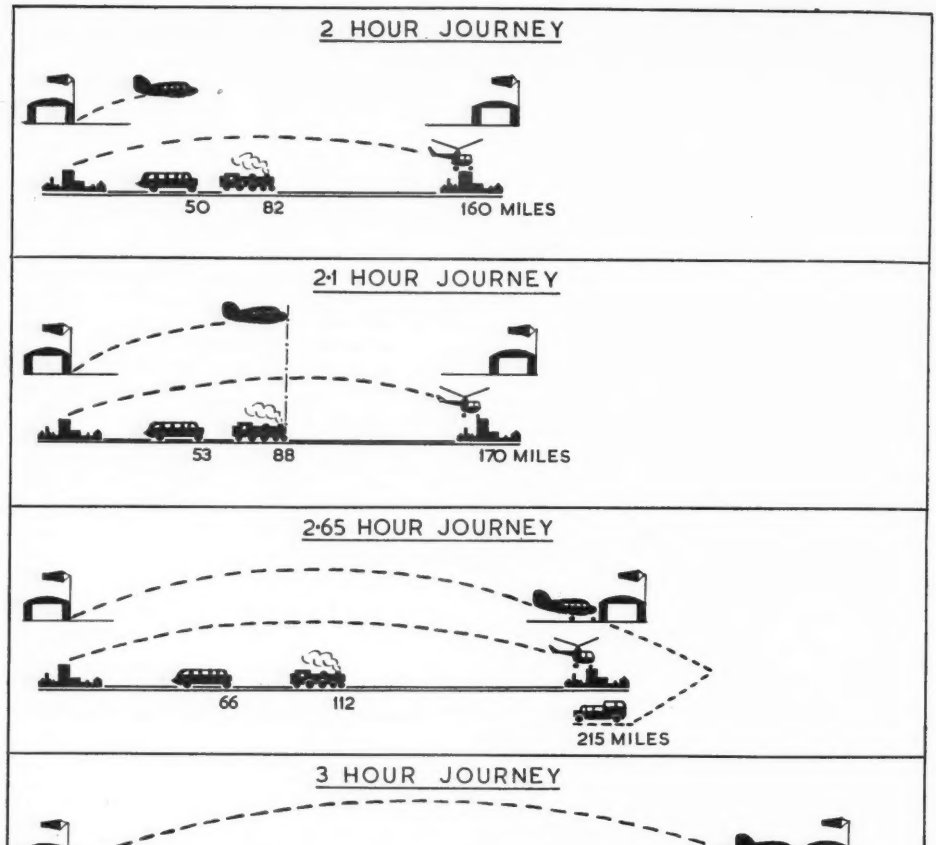


Fig. 57.

Pictorial representation of journey times for various means of transport.
(Assumptions: aeroplane 270 m.p.h., helicopter 112 m.p.h., train 45 m.p.h., bus 25 m.p.h., plus terminal delays and 10 m.p.h. head wind. Figure illustrates relative journey distances covered in specific times.)

passenger mile. Because the aeroplane has a longer journey time than the helicopter for any distance covered in less than 2.6 hours, the aeroplane will be cheaper per hour's duration of journey. But, because it covers less distance than the helicopter in this time, the aeroplane's saving in cost per hour is not significant to the traveller.

Considered purely as a time saver, therefore, the aeroplane is not worth operating in competition with good bus services for distances of less than 60 miles or in competition with a good train service for distances of less than 100 miles. Nor is it worth operating against the helicopter, on equal fares, for journeys of less than 200

miles. These dicta, of course, are related only to the conditions quoted and do not take account of the many special routes, such as short sea crossings, over which the aeroplane can offer substantial savings of time compared with surface transport. Fig. 59 indicates that even for short sea crossings, if the airport is some distance from the city centre the helicopter will save much time over the aeroplane, at similar fares.

As a saver of time, therefore, the aeroplane would not be worth operating at all for distances of less than 200 miles, were good, through, surface or helicopter services available.

The question remains, what are the various forms of transport worth in terms of journey cost related to journey time?

Figures 60 and 60A indicate a possible answer. The extra cost of an hour of time saved on a journey is plotted against distance between city centres. Up to 215 miles the helicopter is the fastest means of transport, thereafter the aeroplane is superior. For a journey of 25 miles the helicopter saves 24 minutes over the bus and costs 13s. 5d. more (five times the bus fare). Even so the helicopter is likely to be losing money, as Fig. 51 shows. The helicopter's saving in time over the bus is at the rate of £1 13s. 7d. per hour saved. On the assumptions made the helicopter is not worth operating in competition with a good bus service for so short a distance as 25 miles. Its saving in time in comparison with a train is insignificant—seven minutes—and the cost of saving it very great; a rate of

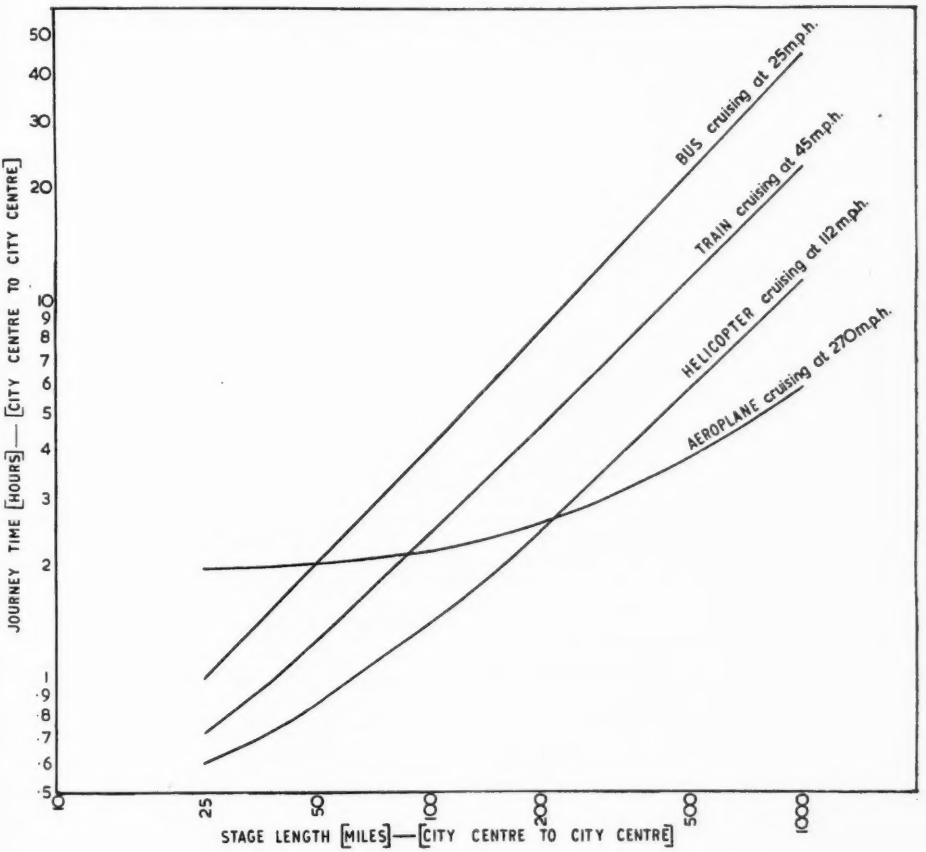


Fig. 58.
Journey Times between city centres for various means of transport.

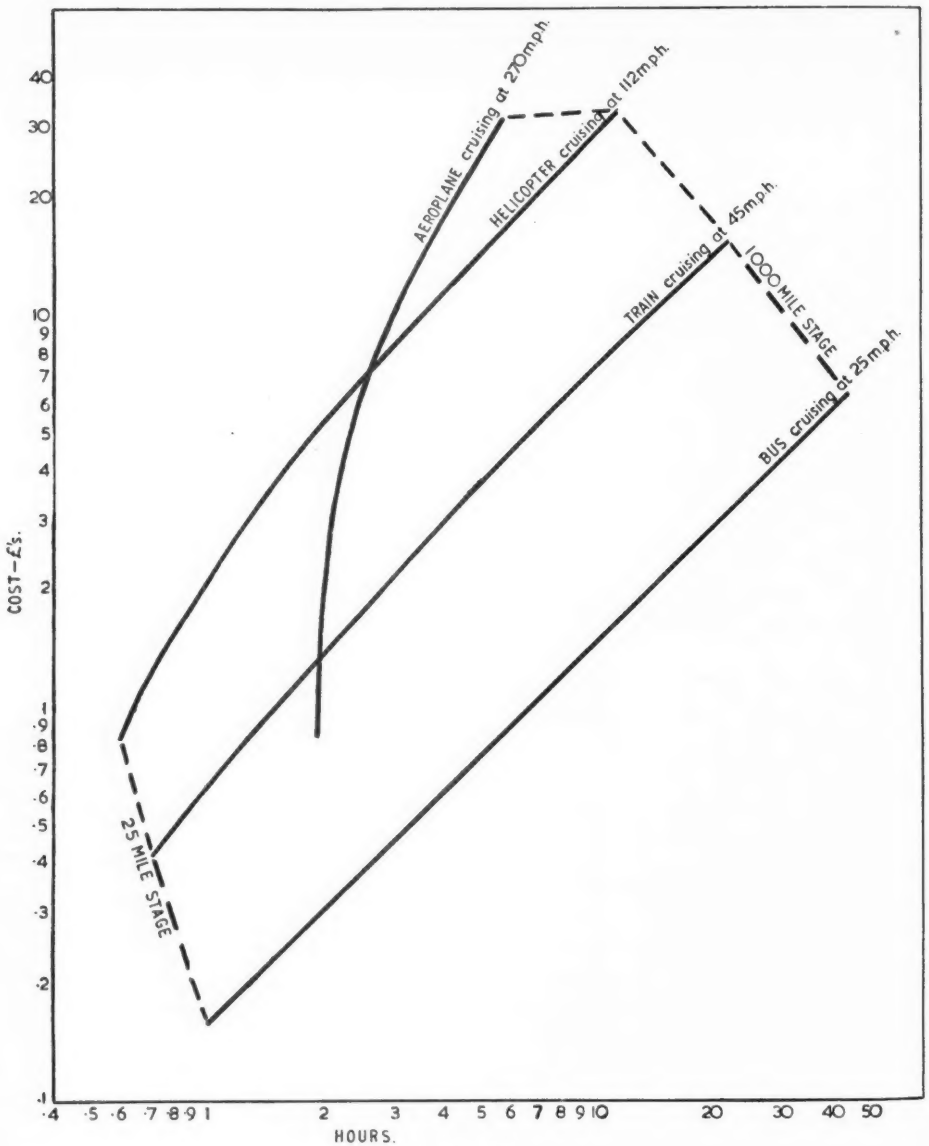


Fig. 59.
Journey Costs related to journey times.

£3 8s. 0d. per hour saved. Therefore, one may conclude that the helicopter cannot compete, at the fares quoted, for a 25-mile inter-city journey.

If one assumes that an hour saved is worth £1, then the helicopter comes into its own compared with the bus for distances of more than 100 miles. At 100 miles, for instance, the helicopter saves 2.6 hours and costs £2.6 more than the bus for the journey.

The depressing fact is that compared with the train the helicopter never costs less than

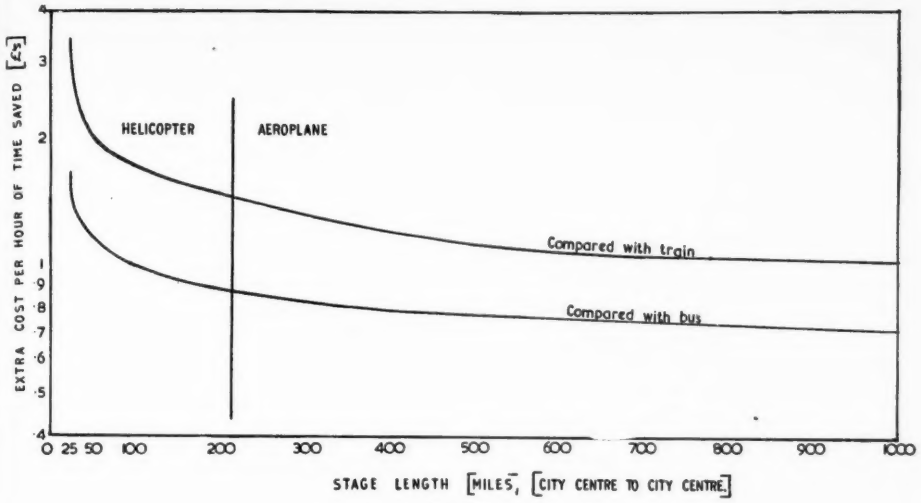


Fig. 60.

Figure illustrates extra cost of time saved for various journey distances, helicopter and aeroplane achieving equal results at 215 miles on assumptions made.

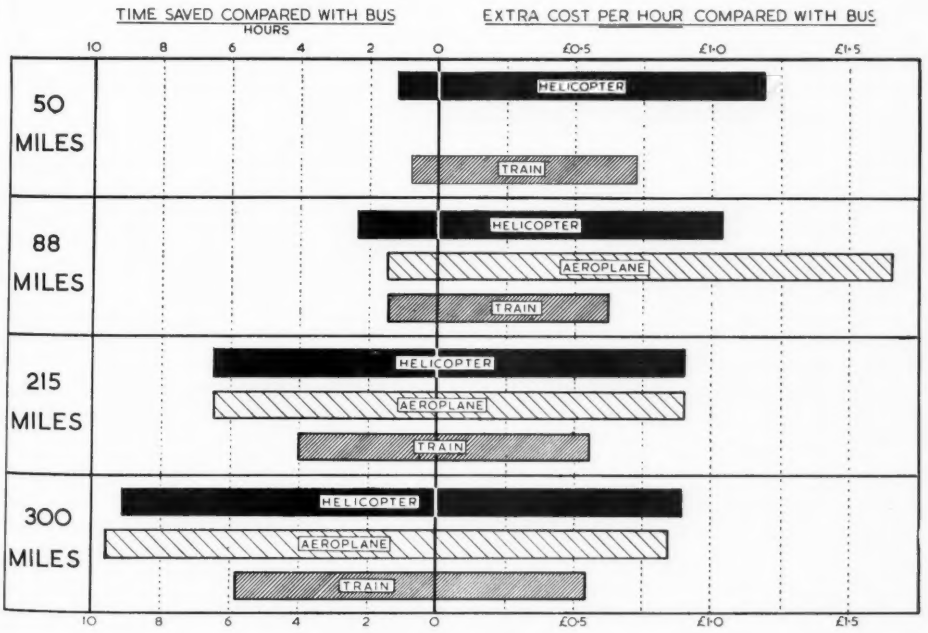


Fig. 60A.

Journey time saved related to cost of time saved. (Bars on left indicate time saved compared with bus. those on right indicate extra cost per hour travelled compared with bus. On the assumptions made, any extra cost of more than £1 per hour will mean that the time saving is not worth while.)

an extra £1 9s. 0d. for an hour saved—and that at the 215 miles distance at which the aeroplane begins to take over.

One may conclude that, on the assumptions made, the helicopter is worthwhile only for short sea crossings, such as Portsmouth to Ryde, Bristol to Cardiff, Liverpool to the Isle of Man, Grimsby to Hull or in the Western Isles, or for cross-country journeys where the rail and bus connections are poor, such as between Cambridge and Oxford, Peterborough and Leicester or Bristol and Southampton, to quote examples in the United Kingdom only.

Compared with an efficient railway service the aeroplane also has a hard struggle. For instance, for an inter-city journey of about 225 miles, such as from London to Plymouth, the aeroplane will save about two hours, taking just over half the time of the train. But the relative costs will be about £3 and £7 10s. 0d. So that for the two hour saving in time the aeroplane will cost about £4 10s. 0d. extra, which is at the rate of £2 5s. 0d. an hour saved. On the representative fares assumed, the aeroplane does not come down to an extra cost of not more than £1 an hour saved until 1,000 miles have been covered. In the United States, air fares are a good deal lower. Consequently the aeroplane is more worthwhile there for shorter distances.

All this tells two stories. First that the prevailing air travel rate of around eightpence per passenger mile on European services is too high to allow the aeroplane to be competitive against fast means of surface travel, restricting the full benefits of air travel to journeys in which sea crossings handicap surface competition. Second, that the speed of air travel is not yet sufficient to reap the full rewards on short journeys in fixed-wing aircraft, largely because of terminal delays. For instance, an Ambassador on a 250 mile stage in a 10 m.p.h. head wind will achieve the very respectable block to block speed of 175 m.p.h. between airports. That is reduced to 88 m.p.h. from city centre to city centre because of the delays at the airports and the slow locomotion through traffic to the city centres. Helicopters from airport to city centre are not an attractive economic solution because they would be operating over a short, and very high cost, stage length.

What then is the solution to this aeronautically depressing state of affairs over short stage lengths—for I am convinced that there is a solution?

Clearly the problem of operating an attractive and an economic air service over a short range between two city centres, well served by railways, is much more difficult than the task of providing air transport over long distances. We have seen already from Fig. 39 that an aeroplane such as the Ambassador can make a profit for stage distances of between 200 and 1,200 miles. By matching the right size of aeroplane to the stage length, "break-even" fares of between fourpence and sixpence per passenger mile could be achieved (Fig. 42), according to stage length.

Applying the desirable objective of air fares kept down to not more than £1 extra cost per hour saved, we can plot the maximum air fare which can be charged competitively. The results on such a basis are encouraging and dispel some of the previous gloom.

Taking the most formidable competitor—the train—we must admit, first of all, that the aeroplane cannot compete for distances of less than about 100 miles at present speeds—leaving aside for a moment the potentialities of the jet. In order to keep the extra costs down to not more than £1 per hour saved, for distances of 100 miles upwards, the air fare would have to be as follows:—

100 miles between city centres. Time saved by air 12 minutes. Maximum permissible air fare 4.48 pence.

200 miles between city centres. Time saved by air 2.09 hours. Maximum permissible air fare 6.5 pence.

500 miles between city centres. Time saved by air 7.45 hours. Maximum permissible air fare 7.57 pence.

1,000 miles between city centres. Time saved by air 16.55 hours. Maximum permissible air fare 7.95 pence.

These figures are plotted in Fig. 61.

The low fare of 4.48 pence per passenger mile for a stage length of 100 miles is not an economic possibility in the present state of aircraft development, leaving subsidies out of account. But the fare of 6.5 pence per passenger mile for a 200 mile journey is well within reach, if mail payments are maintained at present levels.

This means that the aeroplane can be considered a worthwhile competitive commercial

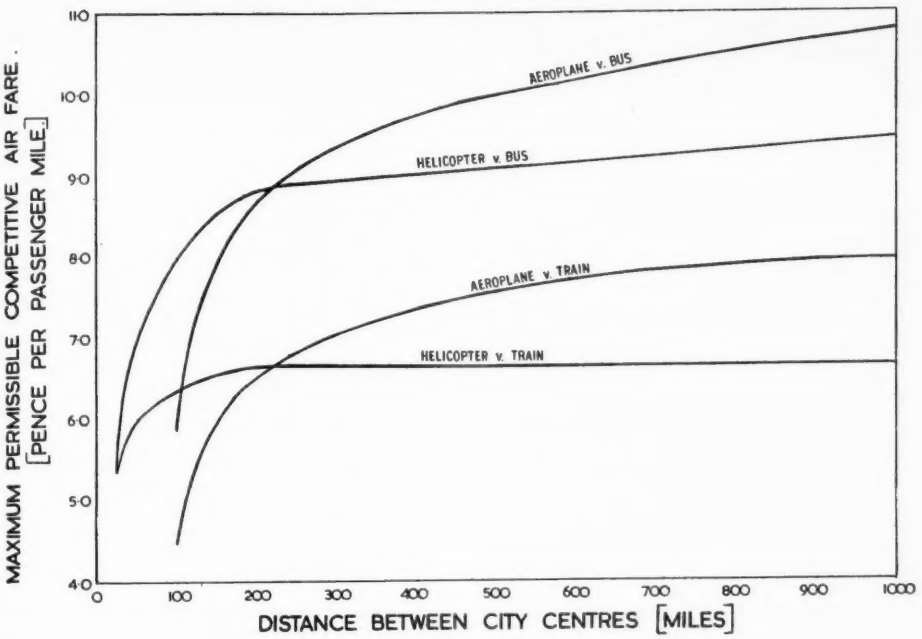


Fig. 61.

Maximum competitive fare related to stage length. (Figure illustrates maximum fare which could be charged by various means of transport so that the cost of saving one hour does not exceed £1.)

proposition at 6.5 pence per passenger mile for inter-city distances of 200 miles or more—provided that the right size of aeroplane is used for the stage distance appropriate to it.

That still leaves a gap for inter-city distances of less than 200 miles—leaving out of account the obvious specialist routes over short sea crossings. The 270 m.p.h. aeroplane having to be counted out for such distances, the 112 m.p.h. helicopter remains as the aeronautical representative. Compared with the train the helicopter fares would have to be kept down as follows, to achieve a saving of an hour at the cost of no more than £1.

25 miles between city centres. Time saved by helicopter 7.2 minutes. Maximum permissible air fare 5.35 pence.

50 miles between city centres. Time saved by helicopter 25 minutes. Maximum permissible air fare 6.0 pence.

100 miles between city centres. Time saved by helicopter 0.98 hours. Maximum permissible air fare 6.36 pence.

200 miles between city centres. Time saved by helicopter 2.22 hours. Maximum permissible air fare 6.66 pence.

These figures are also plotted in Fig. 61.

Fares of less than eightpence per passenger mile are too low to be achieved without loss with the helicopter in its likely state of development during the next few years. Although the helicopter is both faster and cheaper per hour than is the aeroplane for distances of up to 200 miles, the comparison is merely a comparison between losers over such distances.

What can be done to bridge the gap between competitive fares and operating costs, for distances up to 200 miles?

The answer, I suggest, lies through mail. A fast and frequent mail service between city centres would justify a relatively high (but not uneconomic) mail rate. A network of

inter-city helicopter services in the United Kingdom providing much faster postal deliveries than could any other means of transport up to 200 miles would, I submit, be well worth the rather high mail rates (of the order of 20 shillings per ton mile) which would be necessary to prevent losses at a passenger fare of sixpence per mile.* By such a means a public service, unrivalled by any other country in the World, could be instituted, placing Great Britain as far ahead in the new medium as she was 100 years ago in the railway era.

The possibilities are therefore:—

(i) Inter-city helicopter services for distances of not less than 50 miles and not more than 200 miles at fares of sixpence per passenger mile, and

(ii) Inter-city aeroplane services for distances of 200 miles upwards, at similar rates.

The remarks assume of course that a helicopter, at least equal to the hypothetical Twin Merlin Helicopter, can be produced in the United Kingdom within a relatively short time. I am sure that it can.

Analysis of the potentialities of the Twin Transports has shown that, if air traffic control problems can be solved, faster and cheaper services can be secured with turbine aircraft. Because the jet aeroplane would be faster and the saving in time greater, compared with surface transport, higher fares would be permissible. But fares for jet aeroplanes could, in fact, be kept low because of their greater revenue-earning potentials. So, with the jet, the saving of an hour would potentially cost less than £1, while showing a profit.

As usual, it all depends on air traffic control.

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The conclusion of all this is that the helicopter can be useful up to 200 miles if air mail aid is enlisted. Thereafter the fixed-wing aeroplane takes over, the propeller-turbine offering the best economic prospects of all when developments in air traffic control come forward. The jet is faster but even on advanced standards, slightly more expensive per mile. Both would be able to offer competitive services at speeds and rates which would outclass rival means of transport, once the problems of diversion and "stack up" have been solved.

An interesting sidelight on these conclusions is that the average passenger journey on British internal airlines is 155 miles—coming in the helicopter field—whereas the average passenger journey on British Continental services is just under 500 miles—coming well into the fixed wing field and being close to the most economic stage length of the Ambassador.

## 5.4. THE "ORIONS."

### 5.4.1. WEIGHTS AND PERFORMANCES.

Turning now to large long range transport aircraft, I have made a similar analysis to that of the "Twin Transports" comparing four varieties of the hypothetical "Commonwealth and Empire" Orion. The four versions analysed are as follows:—

1. ORION I—(four 5,000 b.h.p. "Orion Major" standard piston engines).
2. ORION II—(four 5,750 b.h.p. "Orion Maximus" compound piston engines).
3. ORION III—(four 5,750 e.h.p. propeller turbine engines).
4. ORION IV—(eight 7,500 lb. static thrust "plain jet" engines).

I have already discussed the Orion I, powered with four 5,000 h.p. Orion Major 28-cylinder four-row radial engines. Analysis of its performance and operating cost has been set out in detail.

The Orion II is assumed to be a development of the Orion I in which the orthodox piston engines are replaced by an improved version incorporating regenerative "feedback" compounding by means of impulse turbo-superchargers, driven by the exhaust, and coupled to the crankshaft through a fluid coupling and gears, with a free-wheel device so that the turbine can drive the crankshaft but the crankshaft can never drive the turbine. Such an arrangement, now forming the subject of work both in this country and the U.S.A., can be used to increase the take-off power by some 15 per cent. and to reduce the fuel consumption for any cruising shaft horsepower by about 15 per cent. The penalty is approximately one additional pound of weight per extra take-off horse-

* Assuming that one letter weighs one ounce and that the average distance of helicopter mails is 100 miles, each letter would cost 0.66 pence to carry. At 2½ pence per letter the Post Office would not be out of pocket on the deal.

power. The problem is largely one of reliability of the turbo-supercharger exposed to the very hot exhaust gases, although the matching of the engine and turbo-blowers and the keeping of back pressures as low as possible are subjects not capable of easy solution.

Assuming here that the problems have been solved, the effect of coupling these exhaust-driven turbo-superchargers to the crankshaft will be to increase the total take-off power available from the 20,000 b.h.p. of the Orion I to 23,000 b.h.p. in the Orion II, for an addition of 3,000 lb. in total engine weight (750 lb. per engine). For the same take-off requirements, therefore, the weight of the Orion II can be allowed to go up by seven per cent. to 214,000 lb. at a penalty of some 1,400 lb. in extra structure weight, 600 lb. in propeller weight and 3,000 lb. in engine weight—a total increase of 5,000 lb. in empty weight for the aeroplane. The net gain is therefore 9,000 lb. in disposable load, plus the reduction in fuel used per mile flown.

The cruising speed of the Orion II will be a little slower than that of the Orion I on similar power, because of the extra weight. I have assumed the same cruising height of 20,000 ft. for both Orions, although, in fact, improved performance would be gained by increasing the cruising height with the compound engines. On the assumptions taken the consumption per hour of the Orion II will be 15 per cent. better than that of the Orion I—coming down to a specific consumption of 0.39 lb. per b.h.p hour. Allowing the same minimum payload for maximum range this approach affords the best possibility of very long range that can be foreseen at present—although it will be less economic for shorter ranges.

The Orion II is thus a 214,000 lb. (95.5 ton) aeroplane, powered with four 5,750 h.p. "Orion Maximus" compound piston engines.

The Orion III is a propeller-turbine aeroplane designed to compare with the advanced piston engines of the Orion II. Four propeller-turbine engines of 5,750 e.h.p. each have been assumed—the absorption of so much power by a propeller of reasonable diameter and high activity being one of the most difficult problems likely to be encountered in practice—as in the other Orions discussed. Multi-blades are indicated rather than the complications and extra maintenance resulting from contra-rotating propellers.

No propeller turbine of this power exists at present—although a developed form of the Armstrong-Siddeley Cobra, once planned for the SR-45, would fill the bill. If sufficient demand materialises there is no reason to suppose that production of such an engine need present exceptional difficulty.

The gross weight of the Orion III can be the same as that of the Orion II for the same take-off performance in standard conditions.

The Orion IV is the final development—powered with eight plain jet engines of an assumed 7,500 lb. of static thrust each. The total thrust available for take-off will therefore be the same as that of the Orion II and III. Again, such engines do not exist at present, although it is not unreasonable to suppose that they will be available when the demand materialises.

Eight engines have been chosen for the plain jet version because of the benefits to be gained from multiple jet engines by operating on a smaller number of engines during descent, diversion to an alternate airport and during stand off. Cruising at a high output from less than the full number of engines is a far more economical method of cruise control during diversion or descent than is throttling a smaller number of engines of equivalent total power. For instance, for the Orion IV the fuel reserves necessary for diversion (500 still-air miles) and stand off (1.5 hours) at 5,000 ft., if four engines of 15,000 lb. static thrust each were used, would amount to about 75,000 lb. (9,250 gallons), whereas using eight engines but letting down, diverting and standing off on only four of them reduces the allowances and reserves needed to "only" about 45,000 lb.—a saving of 30,000 lb.; all of which can go in to the payload. Even this is much too high for economic operations.

So the use of eight engines does not entirely solve the problem. The fuel needed for reserves murders the economics of the aeroplane if the same assumptions for diversion at 5,000 ft. are taken for the jets as for the other types. Therefore I have assumed that air traffic control will have to be improved to an extent at which a jet aeroplane such as the Orion IV could receive its diversion instructions before let down (about 36 minutes from the circuit) and could proceed to its alternate and then stand off *at its operating height*. The result would be to reduce the necessary reserves to just under 20,000 lb. I must stress, however, that these reserves for

## TABLE XXXIII

## WEIGHT ANALYSIS
## ORION LONG-RANGE AIRCRAFT

| | Orion I (four standard piston engines) | Orion II (four compound piston engines) | Orion III (four prop-turbine engines) | Orion IV (eight plain jet engines) |
|---|---|---|---|---|
| 1. Structure weight ... ... lb. | 54,000 | 55,400 | 57,000 | 59,000 |
| 2. Power plant and system weight lb. | 36,700 | 40,300 | 33,000 | 31,500 |
| 3. Operating equipment weight... lb. | 8,100 | 8,100 | 8,100 | 8,100 |
| 4. Passenger equipment weight... lb. | 10,600 | 10,600 | 10,600 | 10,600 |
| 5. Empty weight... ... ... lb. | 109,400 | 114,400 | 108,700 | 109,200 |
| 6. Cockpit crew ... ... ... lb. | 1,150 | 1,150 | 1,150 | 1,150 |
| 7. Cabin crew ... ... ... lb. | 600 | 600 | 600 | 600 |
| 8. Fixed stores ... ... ... lb. | 5,500 | 5,500 | 5,500 | 5,500 |
| 9. Unusable fuel ... ... lb. | 1,450 | 1.450 | 2,000 | 3,000 |
| 10. Basic weight ... ... ... lb. | 118,100 | 123,100 | 117,950 | 119,450 |
| 11. Maximum oil capacity ... lb. | 3,500 | 4,200 | 1,300 | 950 |
| 12. Equipped weight ... ... lb. | 121,600 | 127,300 | 119,250 | 120,400 |
| 13. Maximum usable fuel capacity lb. | 73,880 | 82,180 | 90,250 | 89,220 |
| 14. Corresponding payload ... lb. | 5,000 | 5,000 | 5,000 | 5,000 |
| 15. Usable fuel with capacity payload ... ... ... ... lb. | 53,880 | 62,180 | 70,250 | 69,220 |
| 16. Capacity payload ... ... lb. | 25,000 | 25,000 | 25,000 | 25,000 |
| 17. Disposable load ... ... lb. | 78,880 | 87,180 | 95,250 | 94,220 |
| 18. Gross weight ... ... ... lb. | 200,480 | 214,480 | 214,500 | 214,620 |
| 19. Pre-flight fuel allowances ... lb. | 480 | 480 | 500 | 620 |
| 20. Maximum take-off weight ... lb. | 200,000 | 214,000 | 214,000 | 214,000 |
| 21. Maximum landing weight ... lb. | 170,000 | 177,000 | 177,000 | 177,000 |

the Orion IV would be quite inadequate by present standards. They emphasise again the vital importance of improving air traffic control before jet aircraft can be used economically.

Liberties have been assumed to have been taken also with the airframe of the Orion in its jet version to improve its high speed qualities and also the passenger comfort when encountering gusts or turbulence at high speeds.

The wings and tail surfaces are assumed to have been swept and their thickness-chord ratio reduced. The nose form has been elongated and all excrescences, such as loop and whip aerials, astrodomes and the like, abolished. The problem remains of where to find storage space for all the fuel required—a total of some 11,400 gallons occupying about 1,850 cubic feet. External wing tip tanks might be necessary.

By associating the swept wings with suppression of all external encumbrances and by utilising a high degree of cabin supercharging with the jet engine version, high subsonic cruising speeds can be assumed with reasonable confidence. The problems are immense—those of pressurisation alone being vital to the whole scheme. But only by tackling them can the advantages of the jet be achieved.

Of this jet Orion—as of all jets—it may be said, in the words of my poetical kinsman:

*"A wind's in the heart o' me, a fire's in my heels."*(51)

With the thrust assumed, a nine miles a minute cruising speed, nine miles high, is well within reach.

The significant weights of the four versions of the Orion are as shown in Table XXXIV; full details being set out in Table XXXIII.

Thus the Orion III with propeller-turbine engines has both the largest disposable load and the biggest weight available for fuel. All the "developed" versions come out, somewhat naturally, superior on weights to the Orion I, chiefly because of their higher gross weight associated with lower percentage

TABLE XXXIV

| Weight Summary | ORION I (standard piston) lb. | ORION II (compound-piston) lb. | ORION III (prop-turbine) lb. | ORION IV (jet) lb. |
|---|---|---|---|---|
| Equipped weight | 121,600 | 127,300 | 119,250 | 120,400 |
| Disposable load | 78,888 | 87,180 | 95,250 | 94,220 |
| Max. usable fuel load with 5,000 lb. payload | 73,880 | 82,180 | 90,250 | 89,220 |
| Gross weight | 200,000 | 214,000 | 214,000 | 214,000 |

TABLE XXXVI

| Performance Summary | ORION I | ORION II | ORION III | ORION IV |
|---|---|---|---|---|
| Mean cruising speed (m.p.h.) | 315 | 311 | 392 | 550 |
| Mean cruising height (feet) | 20,000 | 20,000 | 35,500 | 46,500 |
| Mean consumption (lb./hr.) (including allowance for engine maladjustment) | 4,815 | 4,015 | 5,630 | 8,960 |
| Theoretical max. duration (hrs.) | 15.35 | 20.45 | 17.35 | 11.25 |
| Theoretical max. still-air range (no allowances) (miles) | 4,880 | 6,450 | 6,910 | 6,210 |

## TABLE XXXV

## COMPARATIVE PERFORMANCE DATA
## ORION LONG-RANGE AIRCRAFT

| | Units | Orion I (four standard piston engines) | Orion II (four compound piston engines) | Orion III (four prop-turbine engines) | Orion IV (eight plain jet engines) |
|---|---|---|---|---|---|
| 1. Total take-off power ... | e.h.p. | 20,000 | 23,000 | 23,000 | (60,000 lb.) 23,000 |
| 2. METO power ... ... | e.h.p. | 16,800 | 19,300 | 20,200 | variable |
| 3. Cruise power assumed... | e.h.p. | 10,000 | 10,000 | 11,300 | variable |
| 4. Percentage of METO power for cruise ... ... | per cent. | 59·5 | 51·8 | 56·0 | variable |
| 5. Cruising height region—operating height at start of cruise regime... | feet | 20,000 | 20,000 | 31,000 | 43,000 |
| 6. Cruising height region—operating height at end of cruise regime... | feet | 20,000 | 20,000 | 40,000 | 50,000 |
| 7. Assumed average cruising fuel consumption ... | lb./hr. | 4,680 | 3,900 | 6,600 | 8,850 |
| 8. Assumed specific cruising fuel consumption ... | lb./ e.h.p./ hr. | 0·468 | 0·390 | 0·584 | variable |
| 9. Cruising speed at take-off weight ... ... | m.p.h. | 305 | 300 | 370 | 540 |
| 10. Cruising speed at 85 per cent. take-off weight... | m.p.h. | 323 | 311 | 392 | 550 |
| 11. Cruising speed at 70 per cent. take-off weight... | hr. | 339 | 322 | 402 | 552 |
| 12. Mean cruising consumption ... ... ... | lb./ mile | 15·17 | 12·75 | 13·07 | 14·39 |
| 13. Mean air miles per gallon ... ... ... | a.m.p.g. | 0·476 | 0·565 | 0·620 | 0·564 |
| 14. Theoretical still-air range at operating height, no allowances ... | statute miles | 4,880 | 6,450 | 6,910 | 6,210 |
| 15. Estimated take-off distance to reach 50 feet on full power at max. take-off weight ... | feet | 4,100 | 4,100 | 4,100 | 4,100 |

weights of structure and equipment. Of the new versions the compound obviously is the heaviest. But its smaller disposable load is counterbalanced by its very low fuel consumption.

Cruising performance, detailed in Table XXXV can be epitomised as in Table XXXVI.

The compound-piston Orion II has the longest still-air range, closely followed by the propeller-turbine version by virtue of its superior operating height.

But these figures still do not tell the whole story. For commercial operations the appropriate fuel allowances and reserves must be taken into account. I have already pointed out that the turbine-powered aeroplanes can come into their own only as a result of an improvement in air traffic control. Assuming present operating standards for all except the Orion IV and applying specialised but practical operating techniques to the Orion III and IV, the comparative figures shown in Table XXXVII are reached.

From this it will be seen that, in the assumed conditions with 5,000 lb. of payload the Orion II offers the longest still-air stage length, powered with compound piston engines. But using a "turbine technique" the Orion III runs it close and has only five per cent. less range at 20 per cent. greater speed. Against a 90 m.p.h. wind this extra speed will give the Orion III a longer range than the Orion II. The Orion I at the lower gross weight has 72.5 per cent. of the range of the Orion II at approximately the same speed.

The jet Orion IV has almost the same range as the Orion I in still-air (73.5 per cent. of the Orion II) at 66 per cent. greater speed —assuming diversion and stand off at operating height. Were standard reserves included for the Orion IV its maximum still-air stage length would be halved.

These figures mean that on, for instance, the London-New York route, leaving aside the question of economic payloads, whereas the Orion I could maintain a very high regularity westbound with one stop, the Orion II could achieve a non-stop regularity of some 99 per cent. even in the worst season. The Orion III with propeller-turbines and a specialised operating technique could achieve a westbound regularity non-stop of about 90 per cent. in the worst season. The jet Orion IV, like the Orion I, would have to make one stop westbound even with the lenient standards assumed for it.

In other words, the compound-piston engine makes possible the longest range operations, but the propeller-turbine can be brought fairly close to it by taking advantage of every operating device to increase range. On present standards the all-jet transport would be severely handicapped by the necessary allowances and reserves—to such an extent that its range would be considerably less than the version with standard piston engines and it could not get across the Atlantic commercially. When reserves can be cut by improved control methods then the range of the all-jet aeroplane can be brought up to that of equivalent piston engine types of to-day, at a very much higher speed.

The respective Hour Charts show these matters in more detail in Figs. 62 to 64, the block times and payloads in still-air being shown in Fig. 65.

TABLE XXXVII

| Operational Summary | UNITS | ORION I | ORION II | ORION III* | ORION IV (Easier Standards) |
|---|---|---|---|---|---|
| Fuel allowances (taxi, climb and descent) | (lb.) | 11,580 | 12,518 | 12,943 | 18,264 |
| Fuel Reserves (diversion and stand off) | (lb.) | 14,320 | 12,050 | 17,250 | 19,740 |
| Max. still-air stage length | (miles) | 3,435 | 4,730 | 4,490 | 3,475 |
| Block speed | (m.p.h.) | 287 | 289 | 349 | 481 |
| Stage length *v.* 90 m.p.h. wind component | (miles) | 2,451 | 3,356 | 3,440 | 2,918 |
| Block speed | (m.p.h.) | 205 | 205 | 267 | 404 |

* By descending on only two engines and standing-off with one inboard engine stopped and its propeller feathered, the reserves of the Orion III are reduced from the four engine figure of 30,500 lb. to 17,250 lb.—a saving of 13,250 lb., which is available for either payload or range.

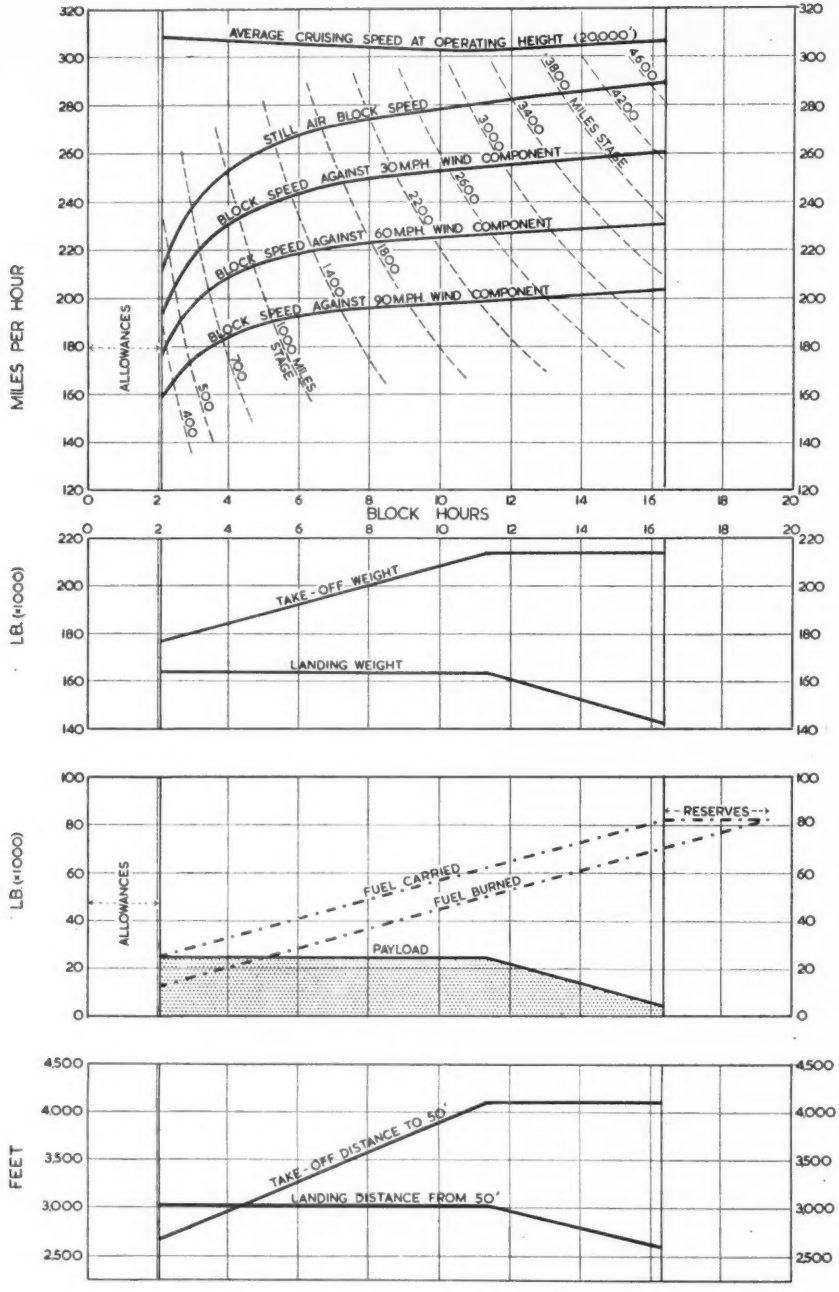



Fig. 62.
Orion II Hour Chart.

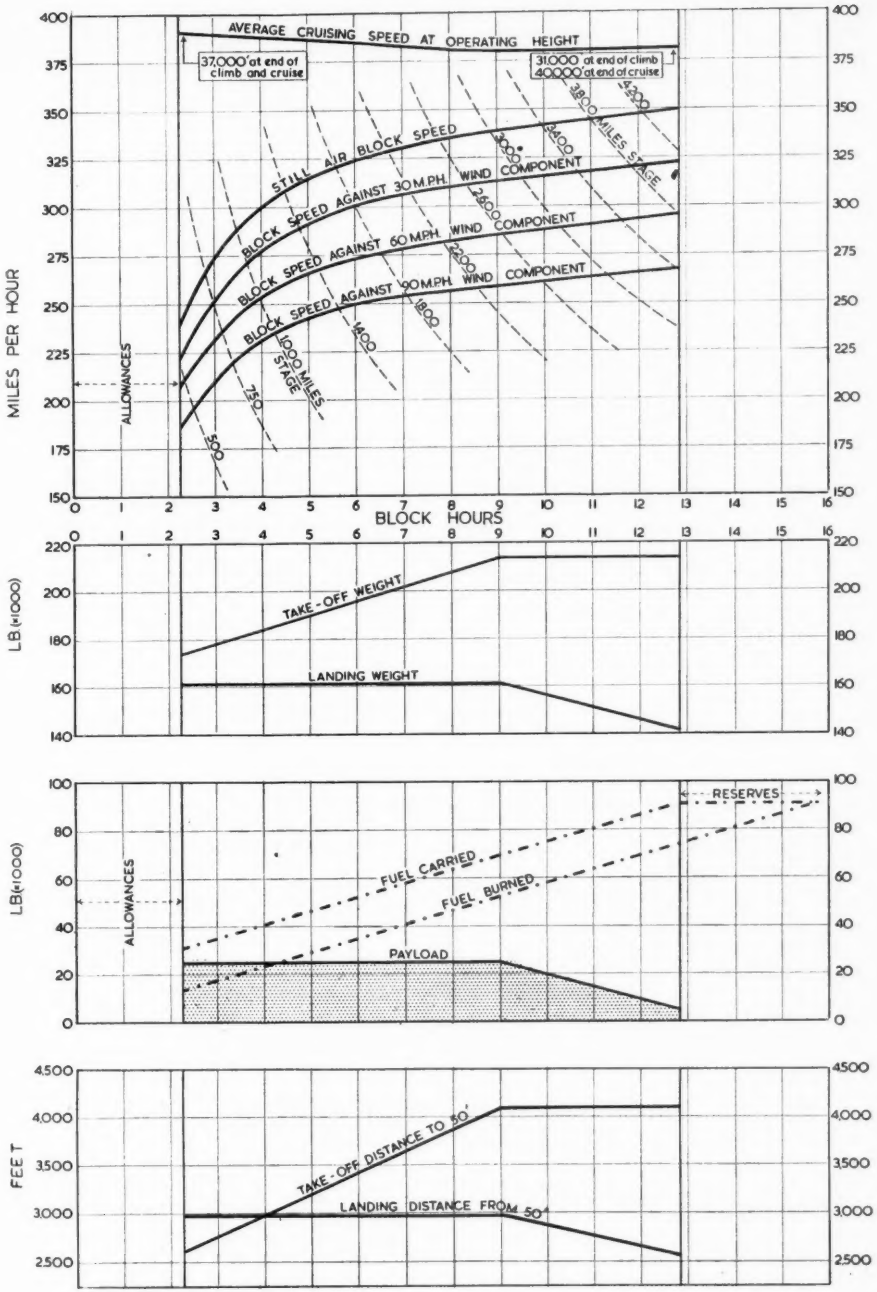



Fig. 63.
Orion III Hour Chart.

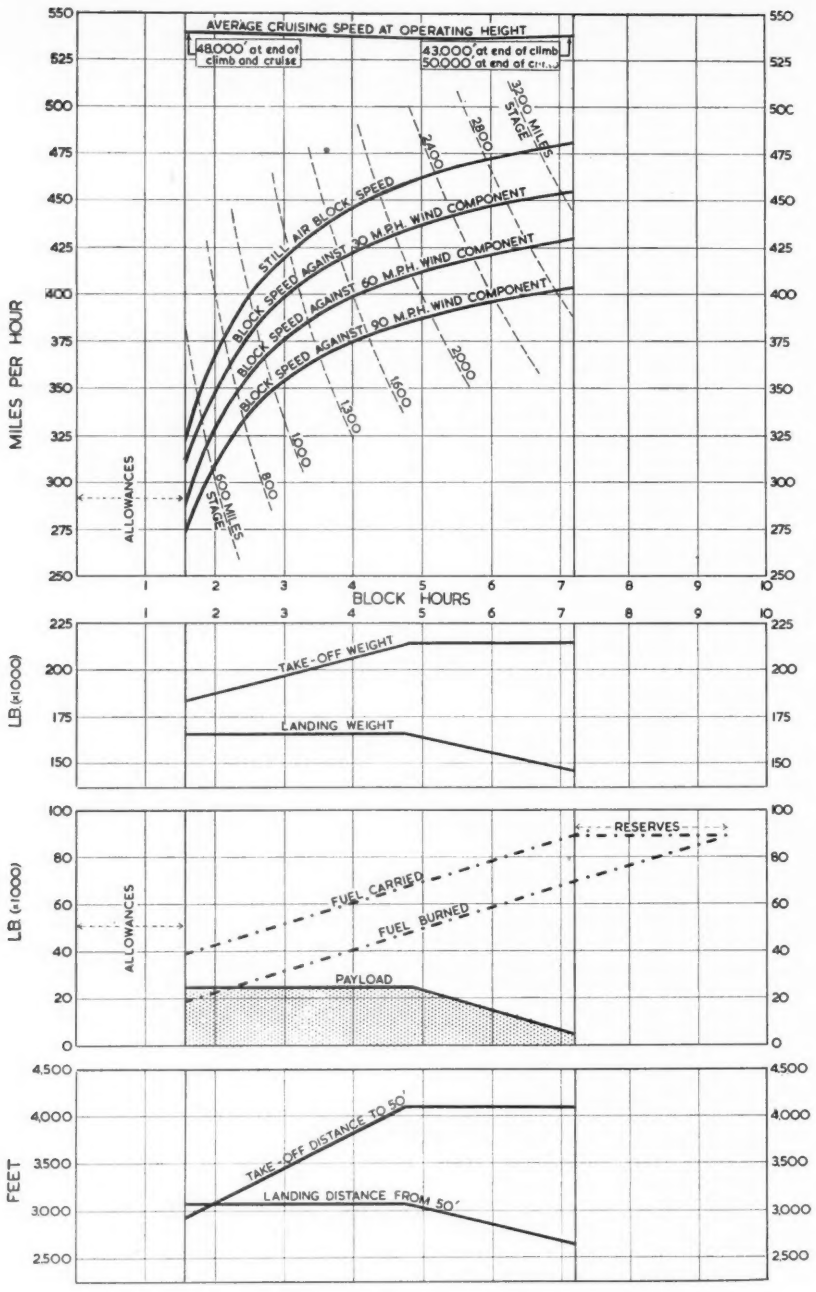



Fig. 64.
Orion IV Hour Chart.

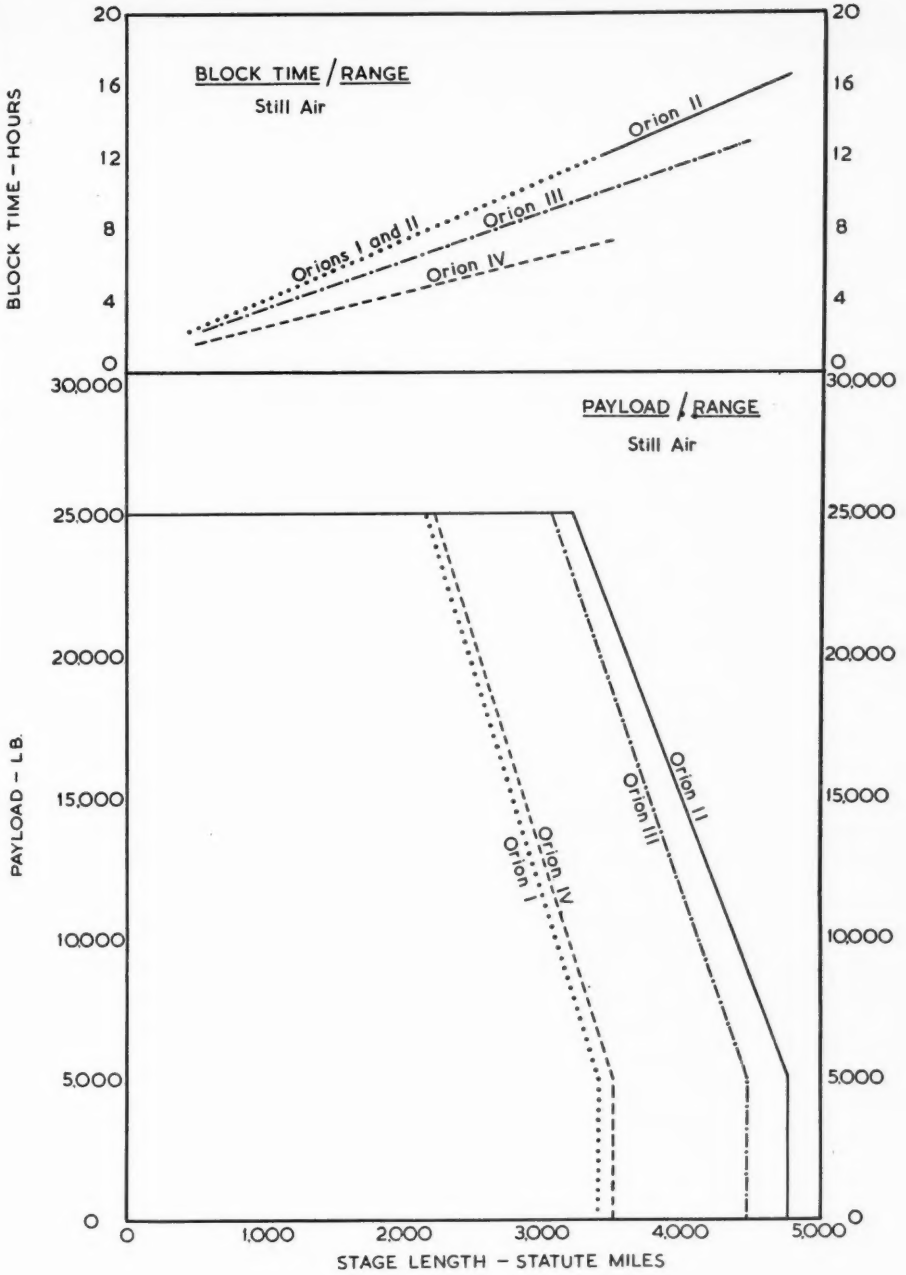



Fig. 65.

Block Time and Payload related to Stage Length—Orions.

5.4.2. LONG-STAGE ECONOMICS.

So much for the performance aspect. Equally important are the Economic Tables XXXVIII to XL.

In summary the costs can be set out as shown below.

These results—with three per cent. added for "dead" flying—are plotted as hourly "cost curves" in Fig. 66, and as comparative "U-curves" of hourly cost per revenue ton in Fig. 67.

Combined with revenue they are plotted as "economic duration curves" in Figs. 68 to 70, the jet Orion IV having a substantial advantage because of its much lighter reserves.

Any stage length and wind condition can be read off the "Hour Charts" and the "economic duration curves" in conjunction. To simplify the issue I have plotted in Fig. 71 the operating costs and revenue for the four Orions in still-air, and in Fig. 72 the same results for a 60 m.p.h. headwind case. Figs. 73 and 74 show the lowest achievable operating cost and the possible profit and loss. Without elaborating in detail, the results on the assumptions taken are as follows:—

The Orion I is profitable on present fares between about 750 stage miles and 2,250 stage miles, with its most economic stage at about 1,650 miles.

The Orion II is the longest range type of the four except in strong headwinds, although it is the highest cost aeroplane for moderate distances. Its effective stage lengths are between 1,000 and 2,600 miles with its most economic stage as 2,500 miles, the exact point depending on wind.

The Orion III shows itself to be a formidable aeroplane for long ranges. Against high winds its extra speed gives it a longer range than the Orion II. The profitable distances at present fares are between 750 and 3,000 miles. Its best distance is about 2,600 miles, the exact distances depending on wind.

The fast Orion IV, operating on easier standards, is profitable on present fares between 500 and 2,650 miles and has its most economic stage length around 1,960 miles.

From these generalisations one can conclude that on present standards there is nothing to choose in operating cost between the 90-ton aeroplane with orthodox piston engines and the similar aeroplane with propeller-turbine engines for stage lengths of up to 2,500 miles in still-air. The propeller-turbine is faster and so will earn more revenue and be a better proposition. For distances of more than 2,500 miles up to about 3,250 miles the propeller-turbine holds the field. Thereafter the compound-piston engine has the advantage by a narrow margin up to the maximum of around 4,000 miles in still-air.

The propeller-turbine and the compound-piston therefore select themselves as rivals for long range operations, with the advantage to the propeller-turbine because of its higher speed.

For shorter ranges in these sizes of aircraft the jet will be supreme once its critical stacking difficulties can be met.

| Cost Summary | ORION I (standard piston) | ORION II (compound piston) | ORION III (prop-turbine) | ORION IV (jet) |
|---|---|---|---|---|
| Fixed annual costs | £332,421 | £354,645 | £391,245 | £351,595 |
| Hourly cruising costs | £146.975 | £141.420 | £173.425 | £151.958 |
| Take-off and landing costs | £387.78 | £417.05 | £394.65 | £408.36 |

For an annual utilisation of 3,000 hours with seven hours between landings, the operating costs will be:—

| | ORION I | ORION II | ORION III | ORION IV |
|---|---|---|---|---|
| Per annum | £938.421 | £957.645 | £1,080,245 | £1,017,198 |
| Per hour | £312 | £319 | £360 | £339 |
| Per still-air stage mile | £1.14 | £1.17 | £1.07 | £0.72 |
| Block speed (still-air) (m.p.h.) | 273 | 272 | 335 | 479 |

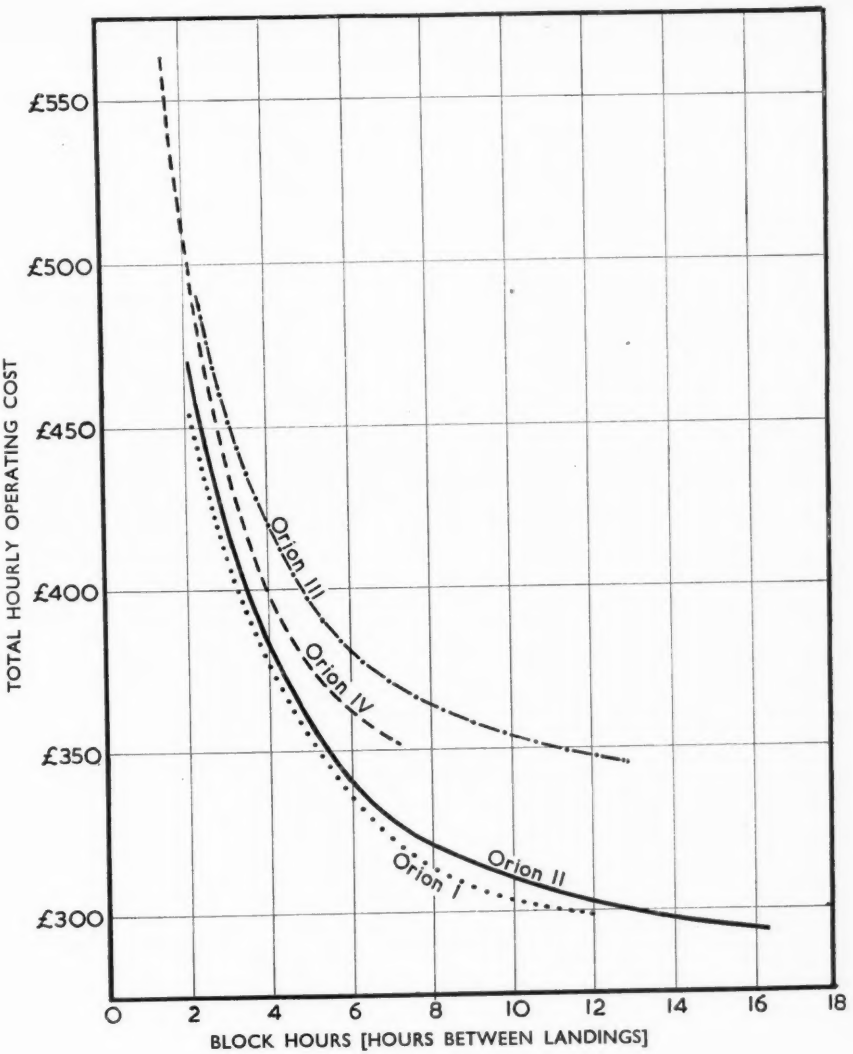



Fig. 66.

Orions.

Related curves of hourly operating cost for various durations.

## TABLE XL

## COST DATA—ORION TYPES
## COSTS OF TAKE-OFF AND LANDING CYCLE

| | Cost Item | Basis | Factors | Orion II | Orion III | Orion IV | |
|---|---|---|---|---|---|---|---|
| 30 | Extra fuel consumed | Extra fuel burned on climb and descent over and above normal cruising consumption in same time | (*a*) Cost of fuel per gall.<br>(*b*) Galls. extra fuel consumed for landing, inc. 3% engine maladjustment ...<br>(*c*) Cost of extra fuel per landing ... | 2s. 0d.<br><br>266<br><br>£26·6 | 1s. 2d.<br><br>Nil<br><br>— | 1s. 2d.<br><br>313<br><br>£18·2 | 30 |
| 31 | Extra airframe maintenance | Extra labour costs at 6d. per ton of airframe weight<br>Extra materials: 3d. per £1,000 of prime cost of airframe | (*a*) Tons weight of airframe ... ...<br>(*b*) Prime cost of airframe ... ...<br>(*c*) Labour costs ...<br>(*d*) Materials cost ...<br>(*e*) Total extra airframe costs ... ... | 33·0<br>£446,000<br>16·5s.<br>111·5s.<br>£6·4 | 33·8<br>£454,000<br>16·9s.<br>113·1s.<br>£6·5 | 34·2<br>£465,000<br>17·1s.<br>116·1s.<br>£6·65 | 31 |
| 32 | Extra engine maintenance | Extra engine labour costs at 2s. 6d. per 1,000 cruising h.p. per landing<br>Materials: 1s. per £1,000 of engine prime cost | (*a*) Cruising h.p. ...<br>(*b*) Engine cost ...<br>(*c*) Labour costs ...<br>(*d*) Materials costs ...<br>(*e*) Total extra engine costs ... ... | 10,000<br>£115,000<br>25s.<br>115s.<br>£7·0 | 11,300<br>£195,000<br>28·2s.<br>195s.<br>£11·1 | variable<br>£115,000<br>20s.<br>115s.<br>£6·75 | 32 |
| 33 | Extra propeller maintenance | 3d. per £1,000 of propeller cost per landing | (*a*) Propeller cost ...<br>(*b*) Cost per landing... | £23,000<br>£0·29 | £23,000<br>£0·29 | None<br>— | 33 |
| 34 | Extra radio maintenance | 9d. per £1,000 of radio cost per landing | (*a*) Radio cost ...<br>(*b*) Cost per landing... | £7,000<br>£0·26 | £7,000<br>£0·26 | £7,000<br>£0·26 | 34 |
| 35 | Landing fees | Up to 20,000 lb., 5s. per 1,000 lb.; 20-25,000 lb., £5; over 25,000 lb., £5 +12s. 6d. per 5,000 lb. Aircraft certified to carry over 40 (inc. crew) and operating outside Europe, 50% surcharge | (*a*) Gross weight—tons<br>(*b*) Landing fees ... | 95·5<br>£43 | 95·5<br>£43 | 95·5<br>£43 | 35 |
| 36 | Passenger ground service | £0·85 per passenger seat on 60% of capacity seats =£0·51 per passenger seat | (*a*) Capacity seats ...<br>(*b*) 60% capacity seats<br>(*c*) Cost of passenger ground service ... | 92<br>55<br>£46·5 | 92<br>55<br>£46·5 | 92<br>55<br>£46·5 | 36 |
| 37 | Station operations and maintenance costs | Average of actual results: £3·015 per ton of gross weight | (*a*) Gross weight—tons<br>(*b*) Stations operations | 95·5<br>£287 | 95·5<br>£287 | 95·5<br>£287 | 37 |
| 38 | Total extra costs per landing | Total cost per landing and take-off | Total ... ... ...<br>Total per ton of gross weight... ... ... | £417·05<br>£4·36 | £394·65<br>£4·17 | £408·36<br>£4·26 | 38 |
| 39 | Totals | Annual fixed costs ...<br>Hourly cruising costs...<br>Landing costs ... ... | per year ...<br>per hour ...<br>per landing... | £354,645<br>£141 8 5<br>£417 1 0 | £391,245<br>£173 8 6<br>£394 13 0 | £351,595<br>£145 4 2<br>£408 7 2 | 39 |
| 40 | Totals per ton of gross weight | | Annual costs per ton...<br>Hourly costs per ton...<br>Landing costs per ton... | £3,710<br>£1 9 7<br>£4 7 2 | £4,095<br>£1 16 4<br>£4 2 8 | £3,675<br>£1 10 4<br>£4 5 2 | 40 |

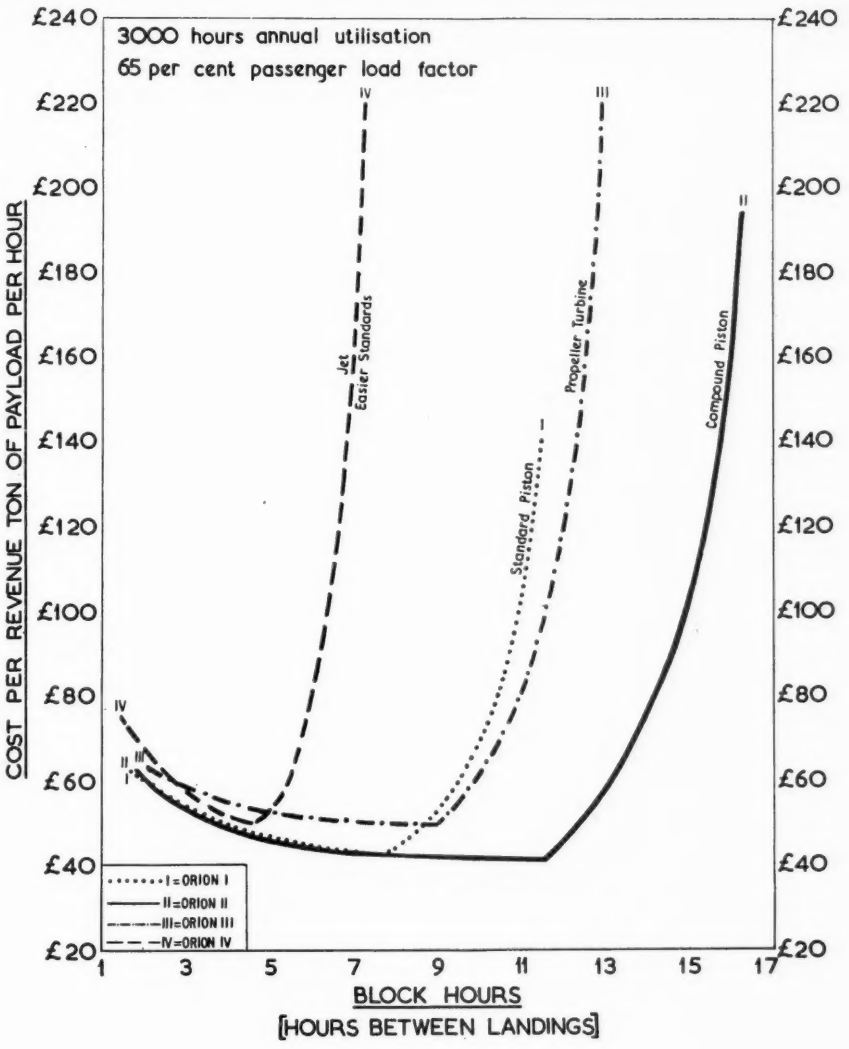



Fig. 67.

Orions—Comparative U-curves of hourly cost per revenue ton.

Fig. 68.

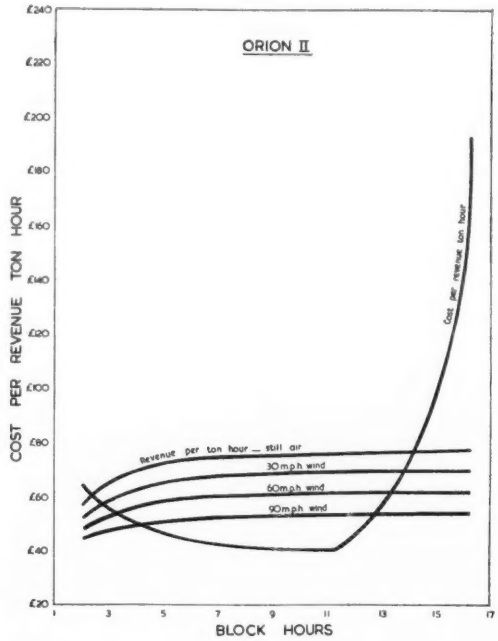



Fig. 69.

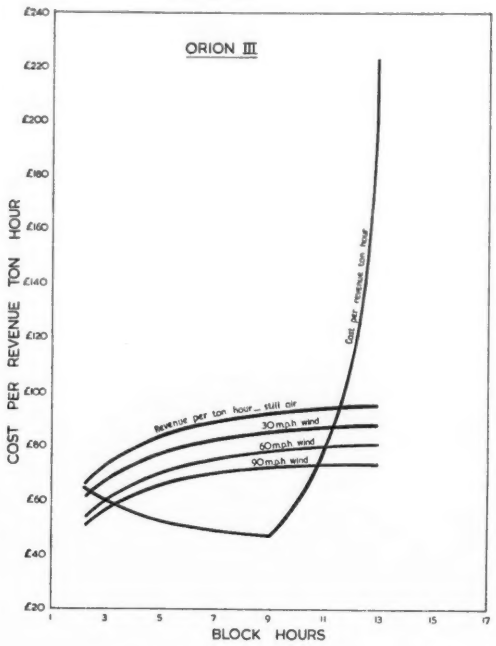
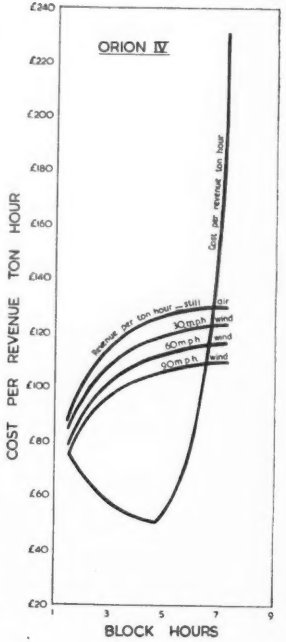



Fig. 70.




Figs. 68, 69, 70.
Orions—Economic duration curves.

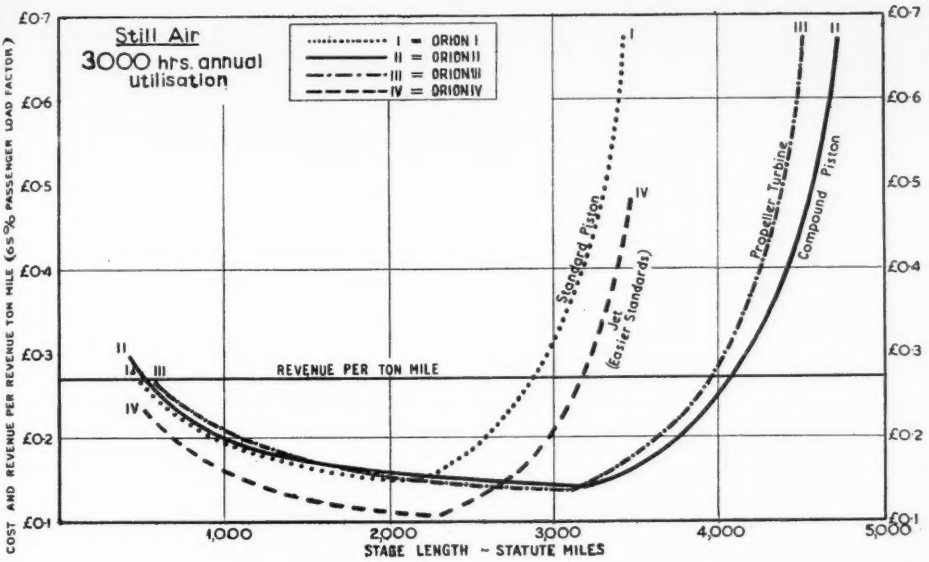



Fig. 71.

Comparative economic stage length curves—Orions, in still air.

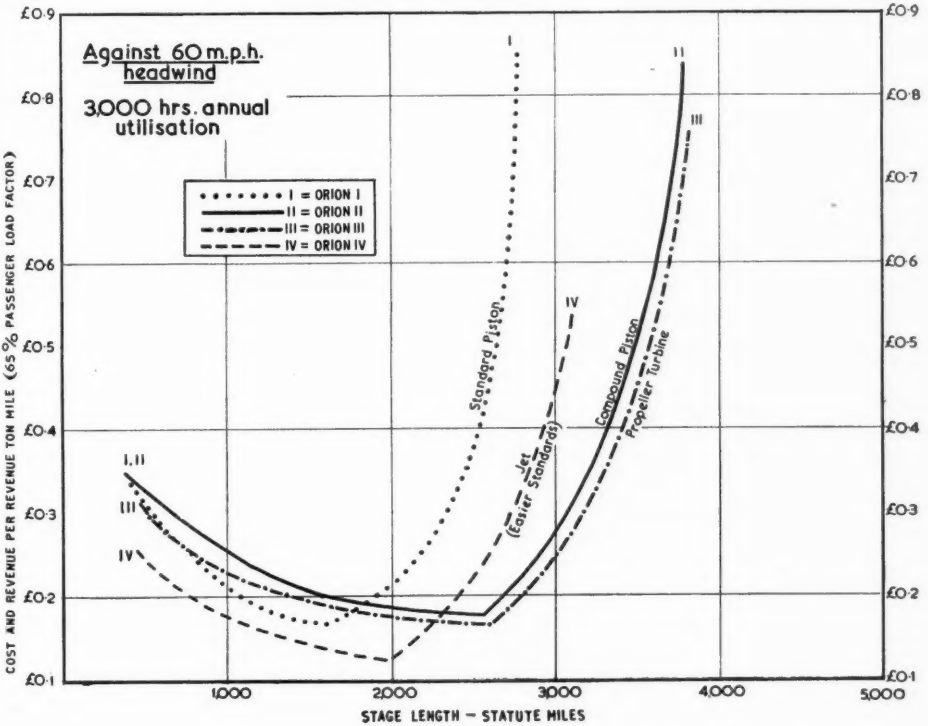



Fig. 72.

Comparative economic stage length curves—Orions, against 60 m.p.h. wind.

5.4.3. NORTH ATLANTIC APPLICATIONS.

A review of the performance and economic characteristics of a range of aircraft of this sort would not be complete unless the conclusions drawn were shown in perspective, applied to a particular route.

Accordingly, to avoid invidious comparisons, the Orions can be treated as guinea pigs and their operating possibilities examined in relation to the most difficult, yet the most profitable, route in the World—the North Atlantic.

As futuristic examples for comparison, the Orion II with compound-piston engines, the Orion III with propeller-turbines and the Orion IV with jets are worth analysis on the route. The Orion I with its standard piston engines, although superior to the Orion II for short stages, is out of the hunt, competitively, for the long stages of the North Atlantic.

The first thing to determine is the limiting route conditions, in particular the stages and winds.

The London-New York flight can be made in a number of different ways (Fig. 75):—

(*a*) *"Round the Houses"*—London-Prestwick-Iceland-Greenland-Newfoundland-New York. (Longest stage: 1,095 miles from Gander to New York.)

(*b*) *Direct, stopping* — London-Shannon-Gander-New York. (Longest stage: Shannon-Gander 1,975 statute miles.)

(*c*) *One stop*—London-Gander-New York. (Longest stage: London-Gander 2,348 miles.)

(*d*) *Non-stop*—London-New York direct. (3,443 miles, Great Circle.)

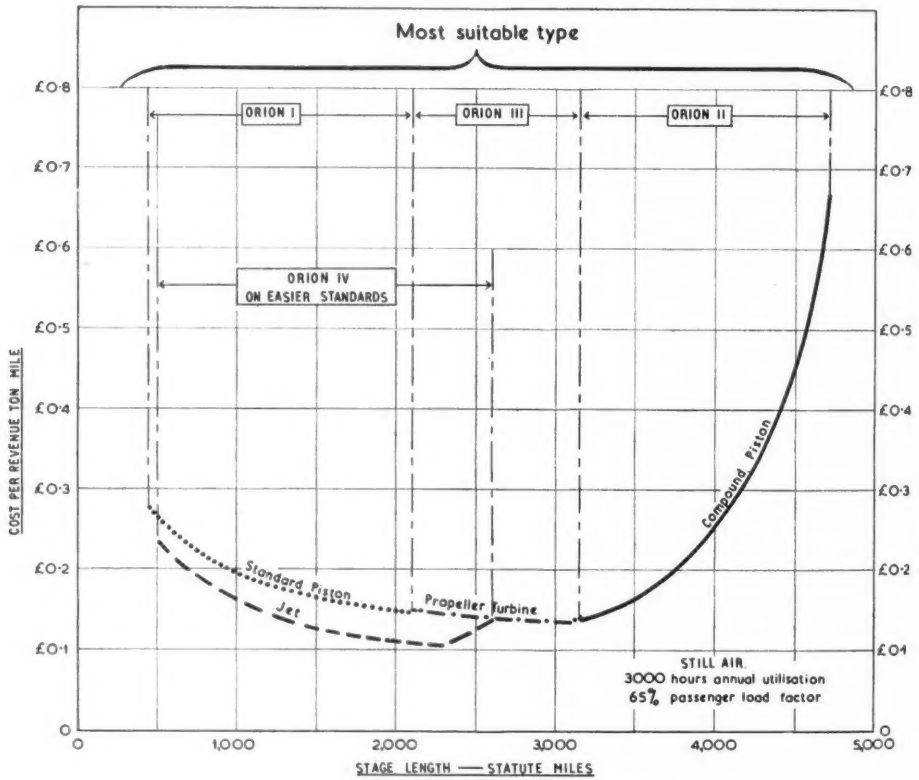



Fig. 73.
Lowest achievable operating cost per revenue ton of payload—Orions.

Ignoring the possibilities of pressure pattern flying and relating direct winds to stages we now have to determine the most economic westbound schedule for each of the three aircraft.

From Fig. 72 we know that, against a 60 m.p.h. wind, the three Orions have the following most economic stage performance (the Orion IV being on "advanced" operating standards):—

Orion I—1,650 statute miles (two stops westbound).

Orion II—2,500 statute miles (one stop westbound).

Orion III—2,600 statute miles (one stop westbound).

Orion IV—1,960 statute miles (two stops westbound).

Therefore, for maximum economy, over routes on which head winds of the order of 60 m.p.h. will be encountered, the various Orions should be operated for stage lengths approximating these distances, the precise stage distance depending on the winds encountered at operating height.

Now, what about the winds?

Figure 76 sets out the North Atlantic wind data related to route and heights. These data have been assembled on the most up-to-date information available. They indicate the somewhat startling fact that the worst height for adverse winds for westbound operations is just the 35,000 ft. at which most propeller-turbine aeroplanes achieve their best performance. Higher than that the winds fall off—and the plain jet aeroplanes achieve their most economic performance. Another interesting fact is that the stage between Gander and New York is the worst for head winds. On that leg the

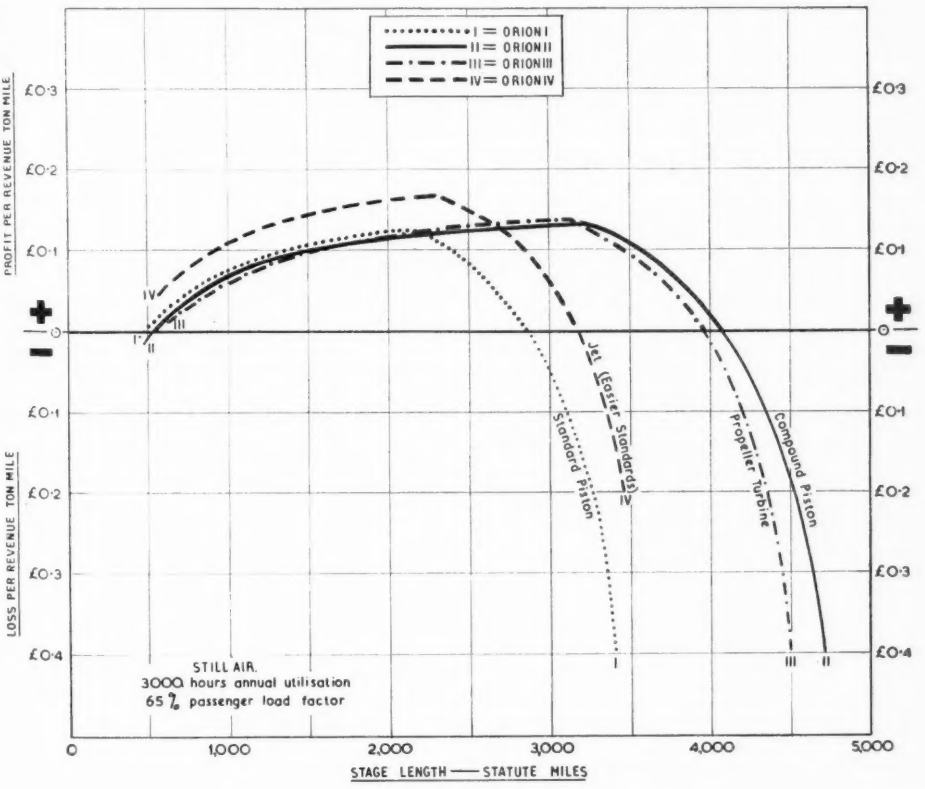



Fig. 74.
Profit and Loss—Orions (Using most economic type).

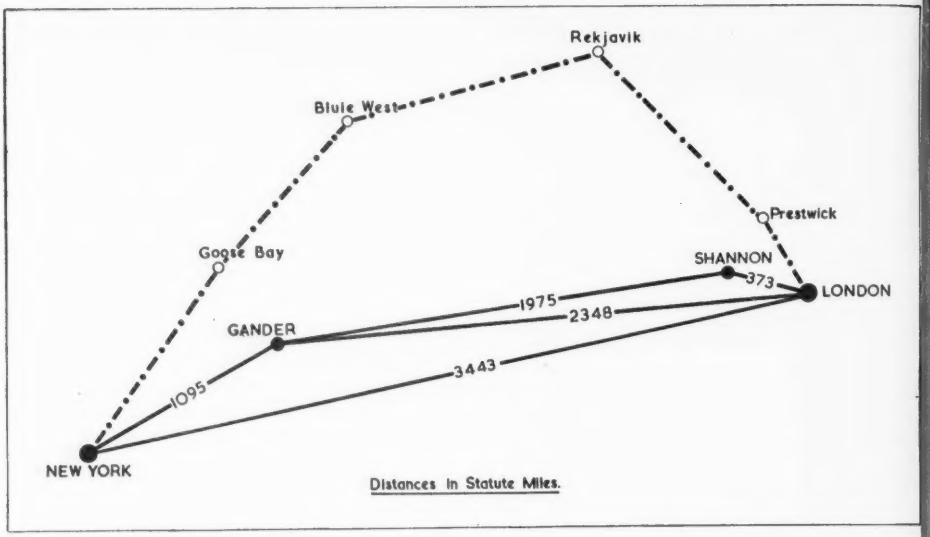



Fig. 75.
North Atlantic Route, U.K.—U.S.A. Alternative Stages. Diagrammatic Map.

"85 per cent. worst season regularity" wind component at 35,000 ft. is more than 100 m.p.h.

Assuming that the four Orions are operated at their mean cruising heights, we can now relate the wind components and the booking payloads which will be achieved over the various stage lengths.

First, London-New York non-stop. The Great Circle distance is 3,443 statute miles from Heathrow to Idlewild. From Fig. 76 we find that at the 20,000 ft. operating height of the Orion I and II the booking payload wind (85 per cent. apparent regularity in the worst season) is 72 m.p.h. From the appropriate hour charts we find that the maximum range of the Orion I against a 72 m.p.h. wind is 2,420 miles. The Orion I is therefore incapable of flying London-New York non-stop with adequate regularity for commercial operation.

The Orion II, on the other hand, can manage a maximum stage length of 3,620 miles against a 72 m.p.h. wind, with all reserves and allowances. For the required 3,443 miles it could achieve a booking payload of 7,000 lb. for the necessary regularity.

At the 35,000 ft. of the Orion III the maximum head wind will be 89 m.p.h. for 85 per cent. regularity. Against this wind the Orion III could achieve a booking payload of 5,000 lb. for non-stop operations—an uneconomic figure when reduced by load factor.

The Orion IV, flying at 46,500 ft., would meet a maximum wind component of 85 m.p.h. Its range would be insufficient for the non-stop flight at the required regularity.

Summing up the London-New York non-stop stage, we find that scheduled operations are not within economic possibilities at the required regularity by any of the aircraft, the Orion II being the nearest candidate with a booking payload of 7,000 lb. The Orions are not big enough aircraft for economic westbound non-stop operations across the North Atlantic at all the year round regularity.

One-stop westbound services are therefore indicated as the next subject for study.

I should explain here that, for convenience in using the generalised hour charts in this route analysis I have assumed that the requirements for diversion to alternate are adequately met by the 500 mile still-air distance set on the hour charts.

When we turn to one-stop westbound services, obviously the least unsatisfactory one-stop operation is provided by using Gander, the stage lengths then being:—

London-Gander—2,348 statute miles.

Gander-New York—1,095 statute miles.

Unfortunately the geographical position of Gander unbalances the stage lengths and prevents application of the most economic size of aeroplane to the job—an Atlantis Island mid-way between London and New York would be a great help towards economic results.

Reading off the "85 per cent. regularity" winds at the appropriate cruising heights from Fig. 76, and applying them to the four aeroplanes, on the London-Gander stage, the achievable booking payloads become:—

Orion I.....12,000 lb.
Orion II.....25,000 lb. (capacity)
Orion III.....25,000 lb. (capacity)
Orion IV.....13,000 lb.

All the aircraft can thus operate the stage. Nevertheless the Orion I is able to carry only half its capacity payload at the target regularity and the Orion IV is some 12,000 lb. down on maximum.

Examination of a two-stop operation by way of Shannon and Gander indicates that the Orion I could achieve a booking payload of 20,000 lb. and the Orion IV, on easier standards, 23,000 lb.

The westbound scheduling would then be:

ORION I—London - Shannon - Gander - New York—booking payload 20,000 lb.
ORION II—London - Gander - New York—booking payload 25,000 lb.
ORION III—London-Gander-New York—booking payload 25,000 lb.
ORION IV—London-Shannon-Gander-New York—booking payload 23,000 lb.

On the return journey, 85 per cent. worst season regularity would be achievable in the following wind conditions:

ORIONS I and II at 20,000 ft.—8 m.p.h. tail wind component.
ORION III at 35,000 ft.—20 m.p.h. tail wind component.
ORION IV at 46,500 ft.—30 m.p.h. tail wind component.

All the aeroplanes would be able to achieve a non-stop operation all the year round with booking payloads as follows:

ORION I..... 5,100 lb.
ORION II.....20,000 lb.
ORION III.....20,000 lb.
ORION IV..... 7,000 lb.

From a commercial point of view the stages should be such that a booking payload of approximately the same weight can be achieved in both directions. Thus non-stop operations on the part of the Orions I and IV would be quite unsatisfactory because the eastbound payload would be far less than the westbound payload. Similarly the payload of the Orion II and III would be reduced by about two tons over their westbound figures. Taking these commercial considerations into account, the most economic commercial possibilities for an 85 per cent. worst season regularity then become:—

ORION I—
*Westbound*—Stops at both Shannon and Gander. Booking payload 20,000 lb.
*Eastbound*—One stop at Gander. Booking payload 22,000 lb.

The commercial round-trip booking payload for the Orion I is therefore 20,000 lb. with two stops westbound and one stop eastbound.

ORION II—
*Westbound*—One stop at Gander. Booking payload 25,000 lb.
*Eastbound*—One stop at Gander. Booking payload 25,000 lb.

The commercial round-trip booking payload for the Orion II is therefore the capacity figure of 25,000 with one stop both westbound and eastbound. Payload and stages for the Orion III come to precisely the same as for the Orion II, at rather higher speeds.

ORION IV (on easier standards)—
*Westbound*—Stops at both Shannon and Gander. Booking payload 23,000 lb.
*Eastbound*—One stop at Gander. Booking payload 25,000 lb.

The commercial round-trip booking payload of the Orion IV is therefore 23,000 lb. for 85 per cent. worst season regularity, making two stops westbound and one stop eastbound.

So the round-trip booking payloads are:—
20,000 lb. for the Orion I,
25,000 lb. for the Orion II and III, and
23,000 lb. for the Orion IV.

The block times for the round trips, averaged throughout the year in the winds encountered, can be worked out from Fig. 76 as follows:—

ORION I—Flying time for round trip: 27.59 hours at 250 m.p.h. block speed with two stops westbound and one stop eastbound. Elapsed time for westbound trip: 18.24 hours at 189 m.p.h. journey speed.

ORION II—Flying time for round trip: 26.32 hours at 262 m.p.h. block speed with one stop westbound and one stop eastbound. Elapsed time for westbound trip: 15.75 hours at 218 m.p.h. journey speed.

ORION III—Flying time for round trip: 22.26 hours at 309 m.p.h. block speed with one stop westbound and one stop eastbound. Elapsed time for westbound trip: 13.82 hours at 249 m.p.h. journey speed.

ORION IV (on easier standards)—Flying time for round trip: 16.25 hours at 425 m.p.h. block speed with two stops westbound and one stop eastbound. Elapsed time for westbound trip: 11.91 hours at 288 m.p.h. journey speed.

At the assumed annual utilisation of 3,000 hours the number of crossings made by each type in a year would be:—

ORION I—108.8 round trips per annum.
ORION II—113.8 round trips per annum.
ORION III—134.8 round trips per annum.
ORION IV—184.5 round trips per annum.

An example of the costing of each stage may be quoted as shown below.

These costs indicate one of the advantages of speed. The jet Orion IV, completing a round trip in just over 16 flying hours, can carry nearly twice as many tons of payload across the Atlantic in the year as can the slower Orion I, which takes more than 27 flying hours for a round trip.

Although the jet costs more for every hour flown, its costs for every ton of payload carried are substantially reduced. On the other hand, were the jet operating on the same standards as the others it could not get across the Atlantic at all with the regularity and payload necessary for commercial services.

When we turn to the subject of revenue, the assumed rates must, obviously, be related to those which are likely to prevail on the

| Shannon-Gander Stage (Westbound) | ORION I | ORION IV |
|---|---|---|
| Distance (statute miles) ... ... ... ... ... | 1,975 | 1,975 |
| Average headwind component throughout year (m.p.h.) | 35 | 46 |
| Average block speed made good (m.p.h.) ... ... | 247 | 420 |
| Average block time for stage (hours) ... ... ... | 8.0 | 4.7 |
| Operating cost per hour for stage ... ... ... ... | £310 | £378 |
| Average cost of operating stage ... ... ... ... | £2,480 | £1,777 |
| Number of one way trips per year ... ... ... ... | 108.8 | 184.5 |
| Total annual cost of operating stage ... ... ... | £269,800 | £337,800 |

Adding up the totals for the various stages flown, the costs work out thus:—

| | ORION I | ORION II | ORION III | ORION IV (on easier standards) |
|---|---|---|---|---|
| Total annual cost | £1,004,500 | £1,005,000 | £1,160,300 | £1,267,700 |
| Cost per flying hour | £335 | £336 | £388 | £422 |
| Cost per round trip | £9,220 | £8,800 | £8,610 | £6,890 |
| Payload carried per trip (at 65 per cent. passenger load factor) | 6.07 tons | 7.59 tons | 7.59 tons | 6.98 tons |
| Total annual payload carried | 1,320 tons | 1,725 tons | 2,045 tons | 2,565 tons |
| Annual cost per ton of payload carried | £760 | £580 | £568 | £494 |
| Cost per revenue ton mile flown | 53 pence | 40.2 pence | 39.55 pence | 34.4 pence |
| Equivalent cost per capacity ton mile | 31 pence | 27.3 pence | 26.9 pence | 23.4 pence |

| | ORION I | ORION II | ORION III | ORION IV |
|---|---|---|---|---|
| | | | | (on easier standards) |
| Total annual operating cost | £1,004,500 | £1,005,000 | £1,160,300 | £1,267,700 |
| Annual revenue | £796,500 | £1,004,000 | £1,232,000 | £1,548,000 |
| Annual profit per aircraft | Nil | Nil | £71,700 | £280,300 |
| Annual loss per aircraft | £206,000 | £1,000 | None | None |

particular route at the dates when the projected aircraft could be in service.

Assuming that the Orions are representative of four possible lines of development in the next generation of aircraft planned for North Atlantic services, and that they are types such as could be in service in the years which, we may hope, will come to be known as the "Flying Fifties"—after this decade of turbulent "Fighting Forties" is over—then the scale of likely changes for this most highly competitive of all routes may be set down as follows:—

*Passenger rate*: 4.5 pence per mile (less 10 per cent. on return tickets).

*Mail rate*: 3.5 gold francs per tonne kilometre.

*Freight rate*: 2.5 shillings per ton mile.

For the Orions these rates would result in a combined revenue of some 42 pence (£0.175) per revenue ton mile or the equivalent of 28.6 pence per capacity ton mile. Each ton of combined payload carried between London and New York would represent a revenue of £604, on this basis.

Matching the revenue and the costs for the various aircraft we obtain the results shown above for the Orions at the above rates, remembering always that the Orion IV is assessed on operating standards which are not yet practical.

Thus, of the aircraft operating on contemporary standards the Orion III with propeller-turbines is much the best; although were the compound piston Orion II flown at a greater height it would come out on the right side, financially, though it could not maintain such fast schedules as the propeller-turbine version. The compound-piston type is very much superior to the standard piston version for long range operations. Should the large propeller-turbine, with its still greater possibilities, take longer to come into commercial service than we hope that it may, then the compound-piston engine—receiving so much attention in the United States—would be able to drive conventional engines off competitive long stage routes.

If, at a later date, an engine becomes available which combines the low consumption and operational flexibility of the compound piston with the high speed attributes of the turbine, it would sweep the board economically.

On the figures analysed, the Orion I with its standard engines, shows a very hearty loss on the North Atlantic. But one must not forget that the aircraft have been assessed on futuristic fares, reduced as a result of competition from advanced types of aircraft. On present fares the Orion I would show a healthy profit. The significant thing is that the Orion III with propeller-turbines is potentially capable of making a profit at fares which are around 65 per cent. of those prevailing to-day and at block speeds 30 per cent. in excess of to-day's levels.

Keeping the mail and freight rates at the assumed figures, and maintaining a 1,000 lb. mail load on each trip, the passenger fares necessary to "break-even" between London and New York, at a 65 per cent. passenger load factor, would be as shown below.

| | ORION I (standard piston) | ORION II (compound piston) | ORION III (propeller turbine) | ORION IV (plain jet) (on easier standards) |
|---|---|---|---|---|
| Break even passenger fare (single journey) | £80 8s. | £61 | £60 | £49 |
| Block speed, round trip | at 250 m.p.h. | at 262 m.p.h. | at 309 m.p.h. | at 425 m.p.h. |

These results, gained objectively, are certainly encouraging. Hedged about, as they must be, by numerous arbitrary assumptions, they nevertheless give support to those who have placed their faith in the propeller-turbine. They are equally encouraging for those who hope great things of eliminating the propeller and depending on the plain jet. The high revenue-earning potential of the plain jet combined with its ability to make fast passages even against strong headwinds —the Orion IV would save just on two hours on each westbound crossing, compared with the Orion III, despite one extra stop—would have very great competitive attractions *once air traffic control has advanced sufficiently to make such operations possible*. On present standards the Orion IV could not fly from Shannon to Gander with sufficient regularity and payload to justify itself commercially. Conversely, were the other Orions operated on the same advanced standards as have been assumed for the Orion IV they would show much enhanced financial results. The Orion III, for instance, would be able to make non-stop westbound crossings with booking payloads near capacity. The saving in time as a result of cutting out stops would bring the elapsed journey time of the Orion III to within a few minutes of that of the Orion IV, with the added advantage of non-stop services.

One should not forget that flight refuelling holds out possibilities of extending range without the delays inevitable as a result of intermediate landings. Flight refuelling has obvious advantages at a non-traffic stop. Tanking up West of Shannon on the westbound crossing should enable the Orion IV to operate through to New York non-stop on most occasions on advanced standards. There are many problems inherent in attempting to flight refuel a jet aeroplane. If they can be solved the advantages in speeding up the journey time are obvious.

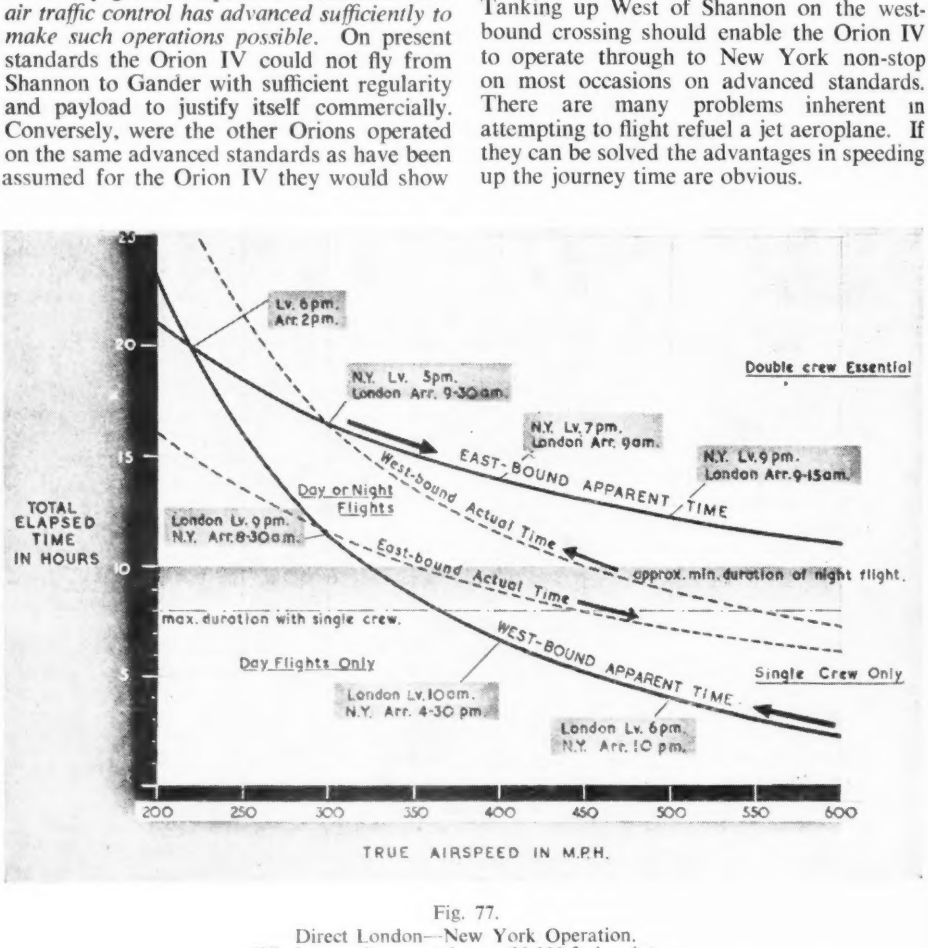



Fig. 77.
Direct London—New York Operation.
Wind strength appropriate to 30,000 ft. in winter.
(Figure indicates elapsed time between London and New York at various cruising speeds and the "apparent time" of journey as a result of difference in times between the two cities.)

How possible journey times fit into the North Atlantic pattern is shown in Fig. 77—for which I am indebted to Mr. C. Dykes of B.O.A.C. At a true air speed of 400 m.p.h., for instance, the London-New York journey could be accomplished non-stop in about 12 hours' elapsed time. As a result of the five hours difference in time between the two cities an aeroplane could leave London at 10 a.m. after breakfast and arrive in New York at 4.30 p.m. in time for tea—or a "coke." The "apparent" time for the journey would thus be 6.5 hours. In the reverse direction with the benefit of the winds, a 400 m.p.h. aeroplane would take about nine hours for the journey. An overnight service, leaving New York at 7 p.m., before dinner and arriving in London for breakfast at 9 a.m. would thus be possible—an "apparent" journey time of 14 hours. These are about the figures which would be accomplished by the Orion III and IV operated on the basis of improved methods of air traffic control.

The advance of the technique of pressure pattern flying, combined with improvements in jet engine consumptions, might make possible economic non-stop operations westbound with a somewhat larger jet aeroplane than the Orion IV. At a true air speed of 500 m.p.h. one could then leave London at 6 p.m. and arive in New York by 10 p.m., with an actual elapsed journey time of nine hours. In the opposite direction a duration of 7.25 hours should be possible, leaving New York at 9 p.m. and arriving in London at 9.15 a.m. next morning, thus cutting out wasted time while sleeping.

Such possibilities are a step ahead of even the hypothetical jet Orion IV and must await aerodynamic, metallurgical and—most important of all—ground control developments. Every improvement will react also on the propeller-turbine and the forthcoming North Atlantic battle between the propeller-turbine and the plain jet is likely to be maintained for a number of years—although other types of power plant look like being eliminated.

My belief is that the propeller-turbine will have a long and profitable innings, in various forms and developments on long range services, before it is finally superseded by the plain jet whose extra speed, when allied with range, will make possible a greatly increased earning capacity and, hence, substantially reduced fares.

Until such time as air traffic control is materially improved, the plain jet aeroplane will be able to perform very fast services over stage lengths for which smaller conventional types of aircraft could carry similar payloads more slowly. Because of its higher speed the jet will be able to provide a much increased revenue-earning capacity. In consequence the bigger plain jet aeroplane, competing with the smaller and less expensive orthodox aeroplane, will be able to operate as economically and provide a more attractive service.

For these reasons, experience with commercial jet transports on short and moderate stage lengths is well worth gaining as soon as possible. Every hour of commercial service flown on specialised routes will bring nearer the time when jet types will sweep the board for all stages from 200 miles upwards. Only experience of commercial operations can provide the data on which developments can be planned. In the present state of the art there seems little object in designing a jet aeroplane of less than about 75,000 lb. gross weight—a minimum size for economic services over moderate ranges in competition with smaller conventional types.

And looking to the future—Shakespeare, as usual, has the words for it:—

> *"And wherefore gaze this goodly company,*
> *As if they saw some wondrous monument,*
> *Some Comet or unusual prodigy."*[49]

As for the Orions—they have served their purpose and can now be returned to the limbo of "pipe dream" aeroplanes. One can say of them that they have served to show that advances are still possible in the piston engine—the compound piston is well worth while over long ranges—but that the propeller-turbine offers greater possibilities still. The plain jet can be supreme for moderate ranges as soon as air traffic control has advanced sufficiently to cut diversion and stacking times.

So, to the Orions "Ave atque Vale."

## 5.5. POWER PLANT PROSPECTUS.

Although aerodynamic developments hold out promise of great advances, all the foregoing underlines the undoubted fact that the type of power plant adopted will influence both the commercial attractions and the economics of a transport aeroplane profoundly.

The orthodox piston engine possesses the merits of reliability and of a thoroughly understood performance. It is at its best in aircraft of moderate size, flying at moderate speeds and heights for moderate ranges. It is in fact a compromise arrived at after 30 years of airline experience.

There can be little doubt that the orthodox piston engine, as we know it to-day, is on the way out, although it will remain in service for many years to come. And in sizes up to 500 b.h.p. an economic successor is not yet obvious.

Compound piston engines, using exhaust-driven turbo superchargers, geared to the crankshaft, show prospects of marked economic advances over the standard engine for long ranges. The foregoing survey, by limiting the compound engine to the same height as the standard piston engine, has somewhat underrated the possibilities of the compound. Flying high for durations of more than about six hours the compound could earn substantially more money for an operator than could a conventional engine in the same aeroplane. The operational flexibility of the compound engine is one of its great attractions over long ranges.

Propeller-turbine engines have many problems of their own, not encountered in the plain turbo-jet. Nevertheless they offer prospects of increased speed over all forms of piston engine without corresponding prospects of increased cost. By taking advantage of height the propeller-turbine can come close to the range of compound piston engines. By taking advantage of speed it can earn more revenue. Through the application of special operational techniques the "stacking" handicap of turbines can be kept within bounds with the propeller-turbine. Leaving aside here the arguments on the relative merits of centrifugal or axial engines and of double or single entry impellers, in my view the propeller-turbine will establish itself firmly as an economic means of transport aircraft propulsion during the next five years and from then on will gradually oust the piston engine in the larger sizes. It will do so chiefly because it will be able to offer greater possibilities of revenue per mile flown.

One stage on towards eliminating the propeller, the ducted fan or "by-pass" engine offers interesting possibilities. The plain jet engine—whether it be axial flow or centrifugal—offers the most attractive prospects of all; combined with the largest number of technical and operational headaches when applied to air transport. For efficiency the jet must fly fast and it must fly high. High speeds present problems of control, of passenger comfort and of structural reliability in turbulence and gusts. Great heights present problems in pressurisation, in cabin heating and in the influence of winds on schedules. Added to these are the predominant problems of air traffic control which I have stressed almost *ad nauseam*. All those problems must be solved before the jet can come into its own.

At present the economic curve of the jet aeroplane resembles a "V" rather than a "U." At its most economic duration the jet transport offers prospects of very low costs per mile. A short distance on each side of that economic range the jet will be very expensive. The matching of a jet aeroplane to the route it is to operate is therefore of supreme moment, while improvements in consumption will help the jet very much, commercially. As things are going at present there are prospects of economic services with commercial jet aeroplanes for medium ranges during the next six years.

From the turbo-jet stem a number of still more exotic means of propulsion, leading us upwards by way of the high subsonic region into the supersonic fields. There the ram-jet and the winged rocket both have applications —and as the science advances both hold out promise of economic commercial operations beyond the speed of sound. Such promise can have no swift fulfilment. The basic fact remains that operating costs are related to hours flown, revenue is related to miles covered. High speeds, resulting in more miles covered in less hours flown, are therefore fundamentally economic, considered in terms of annual profit or loss. That is why the costly train is more worth while than the inexpensive stage coach. And that is why in due course the winged rocket, flying from London to New York in an hour, is certain to come.

Again, I come back to the point that the chief thing which Air Transport has to sell is time. But the speed, which is time, must be offered only in conjunction with

Safety
Regularity
Frequency of service, and
A fare which can be afforded.

Power plant development allied with aerodynamic progression can give us all those—without Heaven too.

# PART IV

## 6. IN CONCLUSION

I have now reached the end of my task. The theme which I have sought throughout is that operating economics, in the broadest sense, are the essence of commercial Air Transport. The purpose of Air Transport is to improve communications—and to improve them economically. Although Air Transport the World over is losing money at present, through a combination of unfortunate circumstances, the facts of the present situation and of developments in train will, I am sure, confound the prophets of gloom. Air Transport, provided with adequate tools and run on the right methods, can be made to pay—furthermore, air travel can be provided economically at fares which the average man will be able to afford.

The last figure—Fig. 78—shows how progress has gone—and will continue to go—inexorably forward. In 1919 when Commercial Aviation began, the fares were around tenpence per revenue passenger mile and cruising speeds averaged 78 m.p.h. Ten years after, in 1929, the fares were about sixpence per passenger mile and cruising speeds had gone up to 105 m.p.h. Ten years later, in 1939, the fares were down to about fivepence per passenger mile and speeds averaged 180 m.p.h. We are struggling to-day with the aftermath of war which has increased fares with speeds. Ten years hence I believe we can look for fares down to those of surface travel and for speeds above the 500 m.p.h. mark. Through the years, a steady advance in speed, a steady reduction in fares. Beyond the turbine era we may look for the era of the winged commercial rocket and, perhaps, of atomic power.

Air Transport is a great and a growing business still in its teething stages. The recipe for the future is a combination of enthusiasm, enterprise, experience, freedom for development and, above all, the pioneering spirit blended with business acumen.

And here I must emphasise again that, in my view, efficient aircraft, matched to the routes they are to operate, are, and will remain, the fundamental factor in the whole Air Transport business.

Efficient aircraft—attractive to passengers,

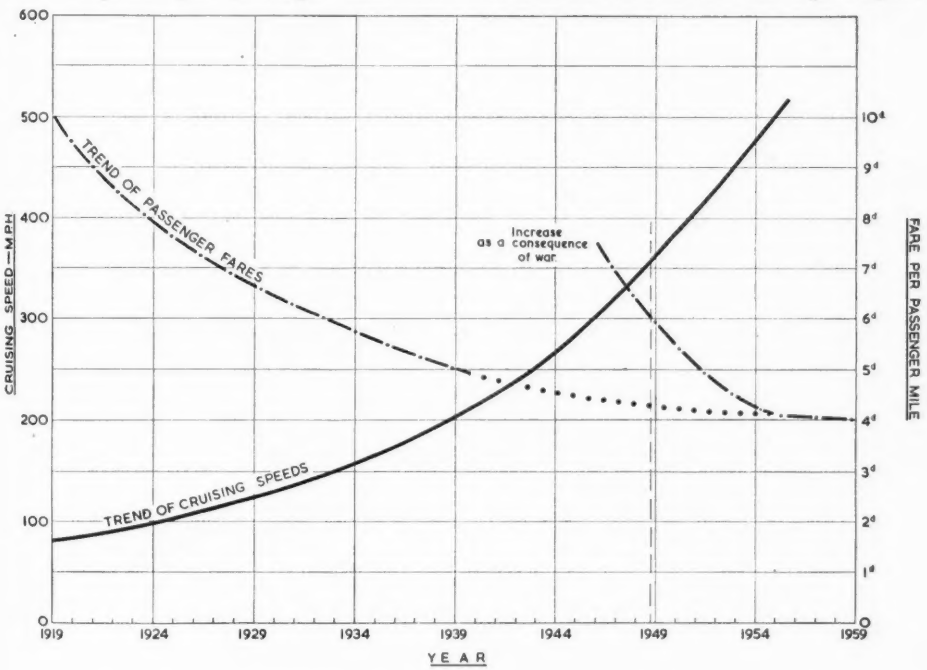



Fig. 78.
Generalised trends of air transport, cruising speeds and passenger fares, 1919—1959.
(Cruising speeds are based on the trend of the best performance achieved in regular service at each date.)

competitive in performance, reliable in operation and economic in service—can be evolved only through a full understanding of the problems involved. Experience is the best guide of all. Indeed, an unfailing maxim of the business is that the more one learns about Aviation, the more one learns that there is still more to learn.

My final note is of confidence—confidence in Air Transport as an economic proposition, confidence that Civil Aviation has a major contribution to make in World affairs, confidence in the ability of the aircraft industries of the World in general—and in the ability of the British Aircraft Industry in particular—to deliver the types of commercial aircraft which will set new standards in performance and economy, and confidence in the air carriers of the World—and especially in the air carriers of the United Kingdom and the Commonwealth—to develop that network of economic services which can provide the finest foundation of a new peace and a new prosperity.

In Air Transport the spirit of a vast new enterprise:—

*"Shall mount on native wings . . . .*
*And cut a path into the heaven of glory,*
*Leaving a track of light for men*
*To wonder at."*(49)

But, because we are still at the threshold of Air Transport's possibilities—which will be carried on like an Olympic flame in generations to come—all this is only The Beginning rather than—

The End.

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A vote of thanks to Mr. Masefield was proposed by Mr. W. G. A. Perring, F.R.Ae.S., Vice-President of the Society, and seconded by Mr. S. Scott-Hall, A.C.G.I., M.Sc., D.I.C., F.R.Ae.S.

**Mr. Perring:** In a very short space of time the British Commonwealth and Empire Lecture, as I think you will agree, has established itself not only as a major function in the Society but also as a major event in aviation during the year. Mr. Masefield had sounded an encouraging and very reassuring note that within a few years civil aviation would be making headway. In the masterly brief survey of the whole situation he had given to-night he came to conclusions which, in his main paper, were summed up in 16 points and I think they may go down in history as Masefield's 16 points.

I believe no one is in a better position than the lecturer as Director-General of Long Term Planning and Projects to give us these conclusions. He has not minimised the difficulties and he has faced the problem, I think, very fairly. He has put great stress on the importance of traffic control. I may perhaps, refer to an incident which happened to-day when the Lord Mayor of London wished to deliver a letter to his opposite number in Paris and show that it could be done within the hour. It was, but it was four hours late in starting. We depend a great deal on air traffic control to improve on that.

I would like personally to thank him for his excellent lecture and I would like on your behalf also to thank him for the brilliant way in which that lecture has been delivered. I feel it

is a lecture which will be one of the finest of this important series and on your behalf and my own, Mr. President, I would like to propose a very hearty vote of thanks.

**Mr. Scott-Hall:** It gives me very great pleasure to follow Mr. Perring in expressing our appreciation of the lecture which we have heard to-night. It gives me pleasure on a number of scores because not only is Mr. Masefield a friend of mine, a member of Council of the Society, but also one with whom I have had the privilege of being associated in the work of our respective departments. He brings many facets to his work. He is a trained engineer and a practical airman. As a writer he has the imagination which sees in aeronautics not only a science but an art. All those who know him well, and I imagine no one in aviation either in this country or outside it has a wider circle of friends than he, recognise in him three outstanding characteristics; an amazing capacity for work, a great charm of manner and sense of humour and, above all, singleness of mind; and I call to mind the words which Charles Morgan used in his famous essay "Singleness of Mind" (I am quoting from memory):—

> "There are great spirits who live not for their present ease but in quest of an impersonal end. As though a runner should spend himself in a relay race for an unknown prize."

Mr. Masefield has likened air transport to an olympic flame and I suggest to you that he is one of the torch bearers. It gives me very great pleasure, therefore, to second this vote of thanks to Peter Masefield for his British Commonwealth and Empire Lecture.

## COUNCIL DINNER

After the Lecture a dinner was given by the Council of the Society at 4 Hamilton Place, at which the following were present:—

Sir John S. Buchanan, C.B.E., A.M.I.Mech.E., F.R.Ae.S. (Vice-President, Royal Aeronautical Society), and Lady Buchanan; Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S. (Director for Construction of Research Facilities, Ministry of Supply (Air), Member of Council), and Mrs. Bulman; Air Commodore H. G. Brackley, C.B.E., D.S.O., D.S.C., F.R.Ae.S. (Chief Executive, British South American Airways); Wing Commander A. A. N. Breckon (Senior Air Staff Officer, Royal New Zealand Air Force), and Mrs. Breckon.

Group Captain C. A. Clarkson, A.F.R.Ae.S. (Civil Air Attaché, Washington), and Mrs. Clarkson; Mr. A. V. Cleaver, A.R.Ae.S. (Special Projects Engineer, de Havilland Engine Company, Member of Council); Dr. H. Roxbee Cox, D.I.C., B.Sc., F.R.Ae.S., F.I.Ae.S. (President, Royal Aeronautical Society, Chief Scientist, Ministry of Fuel and Power), and Mrs. Roxbee Cox; Mr. W. N. Cumming, A.F.R.Ae.S. (Chairman, British Air Charter Association), and Mrs. Cumming.

Dr. G. P. Douglas, O.B.E., M.C., F.R.Ae.S. (Head of Aerodynamics Department, Royal Aircraft Establishment, Member of Council), and Mrs. Douglas.

Mr. Gerard d'Erlanger, C.B.E. (Chairman, British European Airways), and Mrs. d'Erlanger.

Sir A. H. Roy Fedden, M.B.E., D.Sc., M.I.Mech.E., M.S.A.E., F.R.Ae.S. (Past President, Royal Aeronautical Society), and Lady Fedden.

Mr. S. Scott Hall, A.C.G.I., M.Sc., D.I.C., F.R.Ae.S. (Principal Director of Technical Development (Air) Ministry of Supply, Member of Council), and Mrs. Scott Hall; Mr. J. E. Hodgson, Hon.F.R.Ae.S. (Honorary Librarian, Royal Aeronautical Society), and Mrs. Hodgson.

Sir Leonard Isitt, K.B.E. (Chairman of the New Zealand Board of Tasman Empire Airways, and of New Zealand National Airways Corporation).

Mr. E. T. Jones, O.B.E., M.Eng., F.R.Ae.S. (Director of Instrument Research and Development, Ministry of Supply, Member of Council), and Mrs. Jones.

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# CORRESPONDENCE

## MAINTENANCE DESIGN QUESTIONS

Lt. Bowden (Maintenance Design Questions, August 1948 JOURNAL) is to be congratulated on his efforts to bring home to aircraft designers the importance of ease of maintenance, and if the ten questions he has posed could be satisfactorily answered for each component on a new aircraft, there is no doubt that a serviceable aeroplane would result.

In my experience the designing firms cannot possibly have intimate knowledge of the maintenance problems involved and by a "designing firm," one really means the individual draughtsmen, section leaders and so on, whose primary concern is to design a part which will fulfil its design function. As Lt. Bowden infers, the trouble often arises because design is sub-divided into more or less water-tight compartments. Unless there is one person whose function it is to cover the maintenance aspect of the design as a whole, these troubles will continue to occur.

If, as is usual at present, the designing firm does not employ an engineer in this capacity, it becomes necessary for the potential user to ensure that the aeroplane will be to his own maintenance design requirements, bearing in mind his own particular maintenance methods and problems.

The difficulty with this is that the potential user is unlikely to come into the picture in the detail design stage, and the designing firm would probably not, in any case, welcome yet another "snooper."

A partial solution might be to have a standard maintenance check list, on the lines of Lt. Bowden's questions, to be gone through as part of the routine of checking each drawing. Even this would not reveal the type of difficulty which arises through lack of co-operation between different sections, and it is suggested that really comprehensive maintenance trials are the logical answer.

These must simulate, so far as possible, the actual conditions under which the aircraft will be maintained in service: average personnel using standard tool-kits should perform the maintenance operations, not highly skilled firms' service engineers who know the aeroplane backwards and are equipped with all kinds of "wangle" tools. Not only routine maintenance and changes of major components (*e.g.* wing, power plants etc.) should be gone through, but also changes of individual components without disturbing other components, such as items of electrical equipment, hydraulic valves and other components, representative pipe lines, and flying and engine controls. In this connection the "climatic hangar" developed in the United States would seem to offer great possibilities as maintenance operations could be done under all types of weather conditions.

These maintenance trials would have to be made on a prototype aircraft, and any changes incorporated in production aircraft would have to be carefully watched to ensure that ease of maintenance was not impaired. (This occurs frequently during the service life of the aircraft when modifications are embodied.)

Data for subsequent types must be obtained by first-hand observation of maintenance on existing types, by watching the man actually doing the job. It is useless to expect information on maintenance difficulties (as distinct from defects), because usually the operator "binds" to himself or his mates on encountering a snag, and very often it will get no further.

Although designing for ease of inspection, routine maintenance and replacement is important, the essential simplification of the aeroplane as a whole, and freedom from defects, are other factors obviously having a large bearing on overall ease of maintenance.

**E. R. Major,** B.Sc., A.F.R.Ae.S.

My comments on Lt. Bowden's interesting paper are as follows:—

*Question* (3). *Access Panels.*

An unsatisfactory case is quoted but, as is known, manufacturers of oleo legs are usually accessory makers and my contacts with designers of the legs revealed that in most cases they would be willing to place the charging adaptor in a more accessible position, were the point raised by the aircraft manufacturer or buyer.

*Question* (4). *Peaning over of bolts.*

Peaning over threads of bolts is annoying to a good mechanic when dismantling the job and there is a better psychological effect on maintenance staff if split pins and slotted nuts are used.

*Question* (8). *The spare part picking up with existing attachment points.*

It would appear that inspection when checking off the first product, or quantity production, can be of great assistance on the above point.

It is hoped that the paper will stimulate a campaign for easier maintenance of aircraft, which in turn will show effect on greater safety and reliability.

**H. C. Bevis,** A.R.Ae.S.

Although I fear that Lt. Bowden is doomed, as an engineer in the Naval Air Arm, to work with aircraft designed primarily for military duties, one is compelled to sympathise with him in his persistent and justifiable outcry against *avoidable* maintenance difficulties.

Mr. I. L. Hockmeyer made some sound general observations on the subject in the discussion following Professor Lickley's lecture "Evolution of the Design of an Aeroplane" (R.Ae.S. JOURNAL, June 1948), and Mr. A. Smith made a vigorous and obviously heartfelt contribution to the same discussion. Mr. Hockmeyer stressed the desirability of having maintenance in mind throughout all the design stages, while Mr. Smith wanted the prototype to be subjected, before the aircraft went into service, to all the routine servicing, maintenance, overhaul, repair and replacement procedures which it would most require in service.

Both these requirements are ideals which can hardly be realised in practice, but I would like to think that chief designers were only elevated to their position of eminence if maintenance experience were among their qualifications. No designer of naval aircraft could appreciate the significance of Lt. Bowden's remarks with such intimate assurance as he would obtain from the personal experience of servicing one of his firm's machines on a Naval Air station in Scotland through the winter months.

Merely seeing aeroplanes going together in the shops (as suggested by Professor Lickley in his reply to Mr. Hockmeyer) is only a partial remedy, in my opinion, although it would be a useful preventative practice once the awful significance of maintenance limitations had become part of the designer's outlook.

The problem seems to be largely one of specialisation, and the maintenance engineer, being at the tail end of the line, has to "carry the baby."

**S. W. Greenwood,** B.Sc., Stud.R.Ae.S.

Lt. Bowden's paper is factual, and many of the troubles seem so elementary that I wonder if he has been concentrating on one type or manufacturer. As the faults listed have their origin in the Design Office I suggest that some ways in which these troubles could be overcome *at the source* or when they arise in the prototype stage of construction are:—

1. The general requirements of servicing and interchangeability of each component and system to be laid before the senior draughtsman in charge of the particular section at the scheming stage.
2. Parts required as spares to be decided early in the design stage, so that interchangeability is assured and is catered for in the design of the jigs and tools.
3. Removal and assembly procedure for components, *e.g* hydraulic jacks, fuel tanks, in addition to the main components to be checked by the Publications Department from drawings as soon as practicable. This will show up obvious difficulties and the procedure can be finally checked from the aircraft.

4. Snags on assembly, or difficulties of access encountered during inspections should be reported to the Design Department by the inspection and assembly shops as soon as they arise.

These methods succeed if a good team spirit exists between the works and design department, and in each department. Difficulties can then be discussed amicably, a solution mutually agreed upon, and the "paper work" smoothed out to a minimum.

My experience has been that aircraft returned to the contractors for major repairs, in several cases have been repaired previously by service personnel in a method unlike anything in the published repair manual. Do the men who really *do* the job, see the repair scheme?

**G. P. Watson,** A.R.Ae.S.

As a practical maintenance engineer I think the following points are most important:—

1. By the use of commonsense during the design period, no performance need be lost while providing really good maintenance features.
2. The engineers, or their proper representatives, should have proper facilities to criticise the completed prototype, and before that, the completed mock-up, so that any bad points can be rectified before production begins. By this means, the bad points listed by Lt. Bowden could be eliminated almost entirely, particularly for civil aircraft.
3. The prototype should be subjected to all the minor and major servicing, maintenance, overhaul and replacement procedures using only the tools and equipment normally available to maintenance engineers.
4. Untried components should never be fitted to a production aircraft or engine.

All the points listed by Lt. Bowden and scores of others are of real interest to the maintenance engineer.

Regarding civil aircraft of medium to large size, there appear to be two major cases:—

(*a*) Pressurised. Here, the rather obvious impossibility of servicing components in the fuselage from external positions through inspection panels, has not, in the past, resulted in obtaining easy access to components mounted under the floor.

All floor panels, bulkheads, seats, etc., should be quickly and easily detachable and removable, without the need to remove and strip out roof and wall panels, sound-proofing and so on. With civil types, it is often minor, entirely non-structural components and fittings, which cause the delays.

It would also be a great advantage to have as few under-floor components as possible, where foreign matter and water inevitably collect; here such things as combustion heaters are not particularly inviting from a safety viewpoint.

(*b*) Non-pressurised. Although bulkheads, seats and fittings should be quickly and easily detachable with no disturbance to panels, etc., the floor can well be a permanent structure, with all controls and lines under the floor. With large belly inspection panels, a good sized door aft of the cabin to reach the rear end of the fuselage, and a large external nose door, the complete fuselage and all its equipment can be easily serviced.

An alternative is to put the control runs in the roof.

The attachment of the sound-proofing material is often crude and wastes time—great improvements can be made in this direction.

I hope that the discussion of maintenance design problems in the JOURNAL will lead to more attention being paid to a most important aspect of practical aviation and to improvements in the steps taken to ensure that the maintenance angle has not been overlooked in the design of new types.

**A. Smith,** A.R.Ae.S.

## AIRCRAFT ACCIDENTS

The presentation by newspapers of air disasters is certainly not conducive to the public's acceptance of air transport as a safe means of travel. As Mr. Hardingham remarks in his paper ("Aircraft Accidents," July 1948 JOURNAL), although there is justification in some cases for such notoriety, it shows a grim picture to the public, who are the potential ticket buyers on our airlines.

Nevertheless, the frequency and severity of air crashes are far too high, and the "safety" requirement does not seem to be elevated to a high enough position in the scale of requirements of a new design or is allowed to slide down the scale during the development stages.

In the early days of the development of long distance flying, when wooden structures were covered with fabric, and cruising speeds were in the region of 100 m.p.h., accidents were more frequent, but with less loss of life and rarely did fire occur.

The continual striving for more and more speed seems to have superseded thoughts of safety. The air liner is becoming progressively a more and more complicated machine and requires more and more skill to design, build, operate and maintain.

If air transport is to become as safe as the accepted methods of surface transport let us review as follows:—

1. *During the Design Stage*:
   - (*a*) Throughout the development, is the safety angle kept constantly in mind?
   - (*b*) In the event of a crash at high speed will the fuselage structure crumble up, telescope, or otherwise trap the occupants?
   - (*c*) Can the fuel tanks be situated anywhere else than near the power plants, or near electrical services that may set up a spark because of the severing of a lead?
   - (*d*) Have all provisions been made for blind landing conditions?
   - (*e*) What protection has a passenger? (Mr. Hardingham's suggestion of having the seats facing rearwards is excellent but will the public accept it? The psychological attitude of the human being seems to be that if he is going to hit something he wants to see what it is. For example, many train passengers prefer forward-facing seats.)
   - (*f*) What is the ultimate speed in which a human being can stand a sudden arrest of motion such as occurs on flying into a solid object?
   - (*g*) Does the wing loading take care of all possible weather condition loads such as gusts or gales?
   - (*h*) Has every facility been incorporated to ensure correct and thorough maintenance of *all* parts of the aircraft?

2. *During the Operational Stage*:
   - (*a*) Are inspections made thoroughly and is the aircraft correctly maintained?
   - (*b*) Are all considerations observed to ensure the comfort of the crew, particularly against fatigue?
   - (*c*) Is the navigator thoroughly conversant with his course and has he made sufficient allowance for altitude, so that in the event of a change in direction or speed of wind the pilot will not fly into a mountain if the aircraft is slightly off course?

Much is heard nowadays of traffic control at main terminals and the problem of "stacking." Personally, I think that this should be investigated as a traffic problem rather than jump to the conclusion that the only alternative is larger aircraft. It is bad enough to have forty or fifty passengers killed in a crash without having to run the risk of killing a hundred or more.

No design office or airline operator should be without a panel of experts on safety.

**Thos. G. Cribb,** A.R.Ae.S., M.I.Ae.S.

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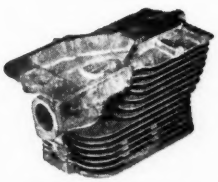

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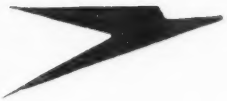
| Vickers-Armstrongs Ltd. | Vickers House, Broadway, Westminster, S.W.1. | Abbey 7777 |
| | Weybridge Works, Weybridge, Surrey | Byfleet 240-243 |
| Vokes Ltd. | Henley Park, near Guildford, Surrey | Guildford 62861 |
| Westland Aircraft Ltd. | Yeovil, Somerset | Yeovil 1100 |
| Wickman, A. C., Ltd. | Tile Hill, Coventry | Tile Hill 66271 |
| Wiggin, Henry, & Co. Ltd. | Wiggin Street, Birmingham | Edgbaston 2245 |
| Williamson Manufacturing Co. Ltd. | Litchfield Gardens, Willesden Green, N.W.10. | Willesden 0073-0075 |
| Yorkshire Engineering Supplies Ltd. | Bronze Foundries, Upper Wortley Road, Leeds, 12 | Leeds 38234 & 38291 |



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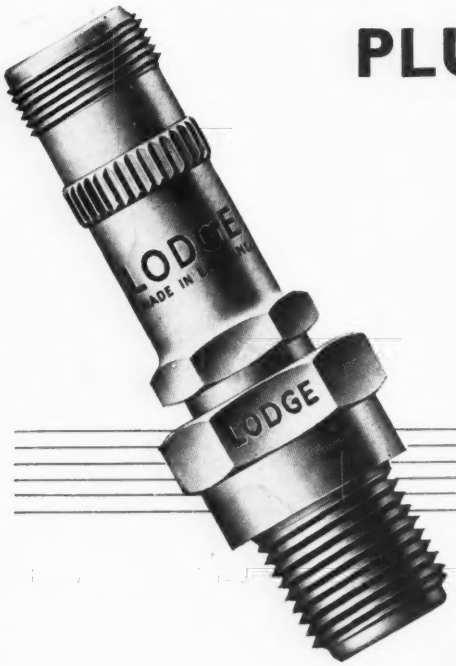


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